FAIR@GSI progress in 2013

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In April 2012 the GSI advisory board requested GSI to establish a line management structure that focuses on the in-kind contributions of GSI to the FAIR project. The result is FAIR@GSI, which was established in August 2012. FAIR@GSI is responsible for the technical supervision of all FAIR accelerators, for the upgrade and operation of the existing GSI accelerator facility and for the procurement of the equipment GSI will provide in-kind to the FAIR accelerators and experiments. In 2013 FAIR@GSI is running with its seven divisions, which cover the accelerator sections and the according experiments as well as project coordination and the cross functional machine tasks. The focus on the project is the scientific and technical work on the work packages defined by the work breakdown structure (WBS). This comprises the technical supervision of all FAIR accelerators, the design and the construction of the systems and components GSI delivers in-kind and the upgrade and development of the GSI accelerator facility. FAIR@GSI delivers the project management for the sub project accelerator. The project coordination organizes the project planning, financial and procurement control, quality assurance, interfaces to the other sub-projects and the documentation and the data handling of project relevant information. In 2013 a solid resource loaded schedule of the project has been established.

In 2013 the collaborations with our partner institutes did progress. MoUs have been established with Budker institute concerning the design and technical supervision on the collector ring (CR) which will be shared in the future. As a start of the collaboration on the CR machine two GSI - BINP workshops have already been held this year, the first one in April and the second one in June 2013. During these workshops, many experts from BINP have visited GSI and discussed together with GSI experts the technical aspects of the CR magnets, the vacuum system design and the power supplies. CEA Saclay is already working on the proton sources and LEBT of the p-linac and will take over the technical supervision of the Super-FRS dipoles. The test infrastructure for the Super-FRS magnets at CERN is progressing due to the substantial support of CERN. The collaboration with Dubna on the SIS100 quadrupole modules and the testing of the quadrupole units is detailed out and contracts are in preparation or have been signed. Finally the collaboration with KVI in Groningen is another strong pillar, supporting the construction of the Super-FRS.

The superconduction (S.C.) magnets for the FAIR synchrotron SIS100

In June the Babcock-Noell GmbH (BNG) delivered the First Of Series (FOS) superconducting (S.C.) dipole magnet for the FAIR synchrotron SIS100. The delivery of the dipole was the first step in the production phase of the heavy ion synchrotron SIS100, the primary beam driver accelerator of the FAIR project. According to the schedule, more than 112 dipole magnets will be produced and delivered to GSI in the next three years. The factory acceptance test (FAT) was successful and therefore the magnet has been prepared for site acceptance test (SAT) at GSI. However about 95 points have been identified in the FAT, which need to be adjusted for the series magnets. The magnet has to undergo a significant number of tests including cold tests. End of 2013 the magnet was tested for the first time at cryogenic temperatures (4 K) under pulse operation conditions. The magnet did exceed its designed performance and quench training went very well.

The ion optical lattice of SIS100 comprises 108 dipole modules and 83 quadrupole modules arranged in the 1086 m long SIS100 accelerator. The 83 quadrupole modules are split into 13 different configurations of arrangements of internal sub-devices. One configuration, appearing in the arc sections of SIS100, was selected to be designed up to a level ready for production. Based on the need of increasing operation safety of the SIS100 machine to a maximum, a consequent reduction of internal interfaces is required. Hence the concept of an integrated quadrupole doublet module was developed at GSI. Within one module two s.c. quadrupole magnets are integrated into a common cold mass, together with further corrector magnets, collimators, bus bar and current lead systems the cold mass is covered in a quadrupole doublet cryostat.

Magnet test facilities

The tests of the several hundred S.C. magnets cannot be done in a single facility. Therefore the different magnets will be tested in three different locations. Prototype magnets and all dipole magnets of SIS100 will be tested at GSI. Significant upgrades to the GSI test facility were needed in order to be ready to test the FOS superconducting dipole. The power converter had to be upgraded to double its maximum current (now up to 20 kA) adjusting its output voltage to the particular SIS100 and SIS300 magnets. High temperature super conductor (HTS) current leads were needed due to the limited cooling capacity of the cryogenic infrastructure at the prototype test facility of GSI. The power converter was optimized and commissioned with a test load. The security off-switch has already been integrated in the power converter. The current leads were delivered to GSI on the 10th of October and then mounted into the feed boxes. The preparation of the series test facility including procurement of the 2 kW cryo plant and the construction of the building for the
cryo plant has been significantly pushed forward in 2013. The S.C. quadrupole units of the SIS100, will be produced at JINR/Dubna. The quadrupole units are combinations of a main quadrupole with a BPM, a sextupole or a steerer. To guarantee conformity of each of the 175 quadrupole units to the technical specifications they have to be subjected to detailed cold tests and measurements that certify the required performance. The according test infrastructure will be developed, manufactured and commissioned at JINR/Dubna. The units of the SIS100 superconducting quadrupole doublet modules (QDM) will be cold tested. This test facility will be available for testing superconducting magnets of the NICA accelerators as well and demonstrates the synergy of the common effort.

The huge Super-FRS magnets, dipoles and multiplets, will be tested at CERN in a collaboration of GSI, CERN and CEA Saclay. CERN will install a test facility with all infrastructure serving three test benches in hall 180. First cleaning and installation work on the infrastructure in this hall has been performed by CERN.

**Preparation for the FAIR rf-systems**

The rf-systems of SIS100 comprises (in the start version) 14 acceleration cavities, 9 bunch compressor cavities and one cavity for barrier bucket operation. For all cavity types, procurement has been started in 2013. A new rf-cavity was developed and realized in the framework of the SIS18-upgrade program in order to increase possible beam intensities for FAIR. The so-called "h=2-system" was developed for the high current operation of SIS18 to flatten the ion density distribution in the bunch and therewith reducing the space charge forces acting on the particles in the bunch. It is essential for the later booster operation for the SIS100 with its high repetition and ramp rate. The "h=2"-cavity has been installed in the shutdown period of 2013 including all infrastructure installations required for the cavity operation. Based on the limited space in the synchrotron tunnel it was necessary to place the high-power-rf-amplifiers (weighting 1 ton) directly on top of the cavity. Due to that the height of the ring tunnel has been enlarged at the location of the cavities. Originally the new rf-system was installed and operated (without beam) in the testing-hall. This required serious efforts, because the supply devices, like the electrical supply from the common net, the oil cooling installation for one unit and the cooling water supply for the other unit, have been installed there additionally.

**Beam cooling in the storage rings**

The collector ring (CR) serves the fast stochastic cooling of antiproton and rare isotope beams. The FAIR Council has allocated the CR stochastic cooling system to GSI as an in-kind contribution. Intensive engineering, manufacturing and procurement activities on various system components have been done in 2013 at GSI. One of the main technical challenges is the cryogenic movable (plunging) pick-up electrodes. After extensive engineering design work, two novel water-cooled linear motor drive units have been assembled in the mechanical workshop and the existing prototype pick-up tank has been modified to accommodate them. These units are easier to maintain and made from aluminium, which is lighter than the previously used stainless steel. Their maximum range of plunging is now 70 mm.

In order to enhance the signal to noise ratio, which is the main challenge for the stochastic cooling of antiproton beams, the movable pick-up electrode modules are thermally coupled to flexible sheets, which are cooled by 2 helium cryoheads to about 30 K. The cryoheads also cool an intermediate cryoshield at 80 K.

**Reconstruction started in cave-B for the CRYRING installation**

In July 2013, the Transport & Installation department (CSTI) has successfully removed the FOPI superconducting magnet from cave-B. The removal of this magnet was an important step for the remodelling of cave-B as a future home of CRYRING@ESR, a Swedish in-kind contribution to FAIR. CRYRING@ESR is a heavy-ion storage ring and will be served with ion beams from ESR or from an independent ion injector. It will first deploy several key technologies for FAIR and serve as an experiment facility on low-energy highly-charged ions. After the move of the magnet the complete reconstruction of cave-B has already started.

**Digital mock-up (DMU) of the FAIR machines**

A very important task is the work in the digital model of the whole accelerator facility, which allows the check for interfaces, collisions with the building infrastructure and the proper alignment of the beam lines to the ion optical lay-out (IOL). This digital mock-up (DMU) is an essential part of the configuration management of FAIR@GSI and is a very successful example for excellent project work at GSI. A 3D-model for the IOL prepared with the beam optic program “Mirko” serves as the backbone for the representation of the beam lines. One of the main jobs of the DMU-team of the mechanical integration (ENMI) department is the visualization of results which have been developed by differenz scientific and technical departments. Many data types have to be transferred into the format of Catia.

As an example the normal conducting (N.C.) magnets are delivered by the magnet and alignment department (ENMA) as 3D-models which will be included in the DMU of the beam lines. After this, the vacuum chambers and diagnostic boxes will be chosen and positioned and collisions will be checked. Defining interfaces for components of different suppliers is one of the major tasks in the developmental stage. Cables, tubes and their ducts and trays towards the components, alignment concept, references, installation space, accessibility, fixation and many more things have to be cleared before the specifications can be released.
UNILAC Status Report

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Maintenance Activities

In 2013 no beam has been provided by the UNILAC; the full year was dedicated to maintenance instead. This chapter summarizes the major works while the second one lists the ongoing upgrade design activities.

Media systems

The water distribution circuit providing cooling for the fourth Alvarez cavity and the IH cavity of the High Charge Injector (HII) has been split into two independent circuits. The measure enhances the temperature stability of the two cavities which in the past suffered repeatedly from difficult incoupling of rf-power. General maintenance was done at the water pumps of the other circuits. The cooling water conduit of the Alvarez section and of the transfer channel was renewed, including provision of de-ionized water for the drift tubes, couplers, and tuners. Many pumps underwent maintenance of the ball bearing and the exchange of oil. The ventilation systems of the High Current Injector (HSI) and the Alvarez section were completely revised.

Cavities

The UHV seals of some Alvarez cavities have been replaced by new ones produced on-site. The repair of UHV leakages at the junction between cavity A2a and the subsequent cavity BB5 required much more resources w.r.t. time and personnel as expected. Repeated leakage occurred after remounting the spokewheels. The same type of work was done at one single gap resonator. The cause of increased reflection of incoming rf-power at the HLI RFQ was identified as mechanical vibrations of the rods, being resonantly amplified at specific time structures of the rf-pulses [1]. The rf-power line to the RFQ of the HSI has been systematically checked in order to identify the origin of rf-reflection; the line proved not to be the cause, we rather assume sparking in the RFQ cavity.

Miscellaneous

The misalignment of the transfer channel beamline due to ground water settlement was quantified. Systematic beam loss surveillance was extended to the areas “transfer channel” and “experimental hall”; several steereers have been equipped with new bipolar power converters.

Upgrade Activities

Compact LEBT

The FAIR requirements on beam intensity of uranium and on the handling of the related infrastructure indicate the installation of a dedicated uranium source terminal together with the subsequent beam transport system. It shall be located between the existing terminals which feed the HSI. As a consequence the latter will not provide uranium in the future. This new branch (Compact LEBT) is under design, aiming at simplified beam optics, i.e. omission of bending magnets and shortening of the line. The expected gain in beam quality will be benchmarked to the todays performance. Details are summarized in dedicated reports [2, 3]. The activities include also studies on improved beam transport through the existing HSI as well as extensive measurements of the beam parameters provided by the existing high intensity uranium source.

Replacement of Alvarez DTL

The existing Alvarez-type DTL, providing acceleration from 1.4 to 11.4 MeV/u, is in operation for several decades. To ensure reliable operation for FAIR it ought to be replaced by a new DTL. The design activities of this new so-called HE-Linac have been started in close collaboration with the Goethe University of Frankfurt. Several options w.r.t. the cavity type are under investigation to ensure that the best choice is made for FAIR w.r.t. beam quality and cost efficiency. For details we refer to [4].

EmTEx

An Emittance Transfer Experiment (EmTEx) aims at demonstration of tailoring the 4d-phase-space distribution of the beam from the UNILAC such that its properties better match to the requirements of the synchrotron SIS18. The proof-of-principle with deuteron beams is foreseen in summer 2014. Last year saw the installation of the set-up in the transfer channel [5, 6].

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Status of the Compact LEBT Project

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To fulfil the intensity requirements for FAIR, a dedicated high current uranium ion source and Low Energy Beam Transport line will be built at the High Current Injector HSI [1]. This new injection line (Compact-LEBT) will be integrated into the existing complex with two branches, designed as a straight injection line without bending magnet (fig. 1). The joint use of the existing matching line (from switching magnet to RFQ) is foreseen.

![Figure 1: Scheme of the Compact-LEBT.](image1)

**Design of the new Beam Branch**

Preparing the design of the new branch, measurements directly behind the ion source had been available with different ions (e.g., argon, tantalum), but not with uranium beams. Now, such direct uranium measurements have been performed at the existing north terminal with the VARIS ion source [2]. The GSI standard mobile emittance device (horizontal and vertical) was used for emittance measurements behind the first triplet of the beam line. To measure the large beam directly behind the terminal, the emittance device from HOSTI was used (large grid size). Also tantalum beam was measured, to allow a comparison of the measurement results from HOSTI and from North Terminal. The good performance of the ion source was confirmed.

Simulations with the DYNAMION code, based on the measurement data, were used to optimize the designed beam line. For the recent design the use of a new quadrupole triplet in the crotch between the existing beam lines, and an already existing quadrupole quartet for focusing behind the terminal is proposed (fig. 2) [2].

**Ion Sources**

Measurements with different ion beams as tantalum and argon have been performed at the high current test injector (HOSTI), to investigate beam intensity and emittance for different extraction- and post acceleration geometries, long run tests of insulator materials, and the suitability of a solenoid magnet for high current operation [3].

![Figure 2: Recent layout of the Compact-LEBT.](image2)

A layout for the new uranium terminal (Terminal West) has been designed (fig. 3). The terminal contains a closed under-pressure system, it houses all sections like a high voltage area with power supplies, transformers and a working platform (closed electrical working area), and a service area with glove box (radiation protection controlled area).

![Figure 3: Principle layout of the Terminal West.](image3)

**Components and Commissioning**

While beam diagnostics components with larger apertures in the existing LEBT are already in operation since 2012, a new quadrupole quartet magnet with enlarged aperture (150 mm diam.) is not yet installed. It was delivered in late 2012, since then precise field mapping has been made. Tendering for the power supply is starting. A new switching magnet and steerers with larger aperture are under design, a new quadrupole triplet can be designed similar to existing triplets. Completion and commissioning are foreseen for 2017.

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A new injection line [1,2,3] is proposed as a part of the upgrade and further development of the high current heavy ion linac UNILAC for the FAIR requirements. The final design of this straight line should be based on precise and complete information about beam current and emittance coming from ion source. An intense experimental campaign was carried out in June-November 2013 at the North Terminal of the UNILAC. Full and self-consistent data for uranium beam including detailed knowledge about the beam current phase density in the transverse phase space has been obtained [4].

As the new LEBT (Low Energy Beam Transport) has no separation by bending magnets, the full spectra of different uranium charge states (2+, 3+, 4+, 5+, ...) will be transported through the line. Then the beam emittance of only design ions U4+ should be matched to the HSI-RFQ acceptance. Although the neighboring charge states could be partly separated at the LEBT, a significant portion of mainly U3+ ions will be also injected into the RFQ. This leads to an increased space charge effects and makes a strong influence on particle motion. Therefore an information about ratio U4+/U3+ is important for proper beam transport and matching. Measurements of beam parameters have been performed at existing UNILAC beam line, directly behind North ion source terminal. Obviously a beam current and beam emittance could be measured only for all charge states together. The standard diagnostics is not able to distinguish ions with different charge states. To solve this problem, a set of measurements behind the first quadrupole triplet (UL4QT1) of the North LEBT was insistently proposed. As it is shown on Fig. 1 (left), a different focusing efficiency for the different charge states leads to a complicated shape of a composite beam emittance.

To distinguish between different charge states a dedicated algorithm was proposed, developed and realized. A macroparticle distribution was generated from the raw data of measured (with slit-grid device) emittance. The density of macroparticles is proportional to the measured intensity in each bin. Beam dynamics simulations with DY-NAMION code have been firstly done backward (upstream beam direction) through the measured magnetic field of the triplet. Two identical distributions, but with different charge state of macroparticles (U3+ and U4+) have been transported separately. In assumption that the beam parameters behind an ion source terminal are the same for every charge state, only a phase space overlapping of resulted particle distributions has been treated as an emittance formed by the complete beam. The obtained “realistic” particle ensemble has been simulated forward (downstream a beam), again separately as U3+ and as U4+. The transported particles at the position of measurements form separately beam emittances for different charge states which perfectly cover the originally measured phase space distribution (Fig. 1, right).

Additionally a dedicated algorithm, based on least squares calculations, provides for an estimated U4+ intensity inside the measured one for all charge states together. With use of this algorithm one can extract from the recent measurements for the mixed beam (U3+ and U4+ mainly) the beam parameters for the design ion U4+ only. The beam current and emittance obtained with different settings of the ion source terminal are in the range of 20-35 mA inside 300-450 mm*mrad respectively. For comparison, the HSI-RFQ high current acceptance with these beam parameters is in the frame of 250-300 mm*mrad.

Generally the proposed coupling of detailed measurements and precise simulations acts as a virtual charge state separator. Being implemented simultaneously for both transverse phase planes, it provides for a better beam transport, refined matching with an RFQ acceptance, as well as for an improved UNILAC performance.

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With the coming FAIR project the requirements for beam brilliance will be significantly higher compared to the values provided by existing high current injectors. Therefore it is planned to build up a separate injector (Terminal West and Compact LEBT) designed specifically for production of high current uranium beams [1]. Also it is necessary to improve and optimize the setup of high current uranium ion sources including extraction and DC post-acceleration systems. These improvements can be performed and demonstrated on high current test injector HOSTI [2].

In 2011 at HOSTI injector the setup has been modified. A new post acceleration system designed for maximum 150 kV voltage was installed. It is much more compact compared to the old one with reduced drift to the first focusing beamline element by 0.8 m. As a result ion beam losses are reduced as well (Fig.1).

Several sets of measurements have been performed at HOSTI using high current non-radioactive ion beams (Ta, Ti and Ar) [3]. Different aspects related to improvement of performance of high currents ion sources were studied: mainly the investigation of beam brilliance of high current Ta-beam provided by vacuum arc ion source VARIS as function of beam aperture. The aperture of the ion beam was controlled with a variable iris installed directly behind the post-acceleration system (Fig.1). The measurements are shortly summarized in Fig.2. It is shown that there is an optimum beam aperture size with highest brilliance between 45 and 60 mm (iris aperture).

Measurements with various apertures of HV-electrodes in the post-acceleration gap have shown a strong influence of electrostatic beam compression in the gap on the beam emittance (Fig.3). Therefore the optimization of electrodes geometry in the post-acceleration system is one of the promising ways to increase the beam brilliance.

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Collimation and decoupling of ECR source beams for brilliance optimization

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Abstract

The four-dimensional transport of the transverse phase space of the extracted beam was calculated for the CAPRICE electron cyclotron resonance (ECR) ion source at GSI. The axial magnetic field adds an angular momentum to the extracted beam, resulting in a strongly \(x-y\) coupled beam. The report presents multi-particle tracking simulations, and the results illustrate that the beam brilliance can be improved by combination of multi-stage collimation with skew quadrupole decoupling.

Quadrupole Collimation Channel

The quadrupole collimation channel is placed behind the analyzing magnet in order to improve the beam brightness. An uncorrelated beam with desired Twiss parameters is assumed at the entrance of the quadrupole collimation channel being the periodic matched solution of the channel. Only particles in a defined phase space volume are transmitted through the entire channel, all other particles are stopped at the apertures along the channel. The magnetic quadrupole collimation channel has three cells including three identical magnetic quadrupole doublets and four four-jaw slits. For efficient and flexible collimation, each cell is set to cause a phase space rotation of 45 degree and multiple cells with overall phase advance rotation larger than 90 degree (145 degree in this channel). Four successive four-jaw slits are used for multi-stage collimation with the phase space rotation in between [1].

Skew quadrupole decoupling section

After charge-to-mass selection, two normal quadrupole doublets are used to match the analyzed beam into the quadrupole collimation channel. The quadrupole collimation channel, which consists of three normal quadrupole doublets with the same gradient but alternating sign are used to carry out the multiple-stage phase space rotation. The decoupling section comprises two normal quadrupole doublets and one skew quadrupole triplet, and their gradients are optimized by a numerical routine to remove the inter-plane correlations, thus minimizing the product of the horizontal and vertical rms emittances [2].

Collimation and decoupling simulation

In general, an ECR ion source beam possesses a large beam size and divergence. Therefore, higher order effects (aberrations) can not be avoided inside the solenoid. If the particle deviates from the center of the solenoid, it feels a non-linear force and the non-linear force causes the rms emittances and eigen-emittances to grow. Once the beam enters the analyzing magnet the horizontal rms emittance starts to increase gradually, but the vertical rms emittance is not changed. After charge selection, if the collimators are not adopted to cut particles, the rms emittances and eigen-emittances are almost constant until the first skew quadrupole. If the collimators are adopted, utilization of collimators stepwise decreases the rms emittances and eigen-emittances in the matching section. Inside of the skew quadrupole triplet, rms emittances are made equal to the separated eigen-emittances.

The behaviors of dimensionless brilliances and the transmission efficiencies along beam line with (horizontal half slit width \(h=2\text{ cm}\) and vertical half slit width \(v=2\text{ cm}\)) and without collimators are shown in Fig. 1.

![Figure 1: Dimensionless brilliance and transmission efficiency evolutions along the beam line with (solid lines) and without (dash lines) four successive slit collimators.](image)

References


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Upgrade of the HLI microwave system

In the last years several experiments using the technique of frequency tuning were carried out at the ECR injector test setup (EIS) of GSI in order to investigate the influence on the performance of the CAPRICE-type ECR Ion Source (ECRIS) in terms of enhanced ion currents of high charge states [1] [2]. It was demonstrated that this technique allows increasing the ion current extracted from an ECRIS both for gaseous and for metallic elements [3].

In order to use this technique for the routine operation of the ECRIS installed at the high charge state injector (HLI) of GSI, the microwave injection system has been modified. Figure 1 shows a schematic view of the upgraded microwave system. A signal generator provides the microwave signal to be amplified by two traveling-wave tube amplifiers (TWTAs). Each of them provides up to 650 W in the frequency range 12.75-14.5 GHz. When the required power is higher than 650 W, i.e. for Ca or Ti beam production, the power of the two amplifiers is summed up through a WR62 waveguide power combiner. The system is integrated into the existing waveguide system with a WR62 mechanical switch. With this versatile setup the microwave input can be switched from the waveguide line connected to the klystron to the one where the upgraded system including the TWTAs is installed. Two directional couplers are inserted between the switch and the ion source. Microwave power probes are connected to each directional coupler to measure the forward power and the reflected power to and from the ECRIS. The knowledge of the reflection coefficient is beneficial to optimize the microwave coupling to the plasma which is a fundamental condition for a good performance and stable operation of the ECRIS [1].

X-ray spectroscopy

In the framework of the ENSAR-ARES collaboration (supported by the European Union Seventh Framework Programme FP7/2007-2013 under EU grant agreement n° 262010) various experiments have been carried out on the investigation of X-ray emission from the CAPRICE ECRIS. The measurements were performed at the EIS test setup by using two different detectors. A Silicon drift detector (2-30 keV) has been mounted at the extraction electrode, and a high purity Ge detector (30-500 keV) has been placed behind the analyzing dipole magnet in 0° direction, respectively. The experiments were performed at different settings of the confining magnetic field and at different microwave frequencies to characterize the electron energy distribution and to investigate correlations with the charge state distribution (CSD) of the extracted ion beam. Results show that the tuning of the heating frequency considerably affects the plasma density. Details are reported in [4].

Beam profile measurements

Ion beams extracted from an ECRIS are in most cases characterized by an internal structure with inhomogeneous current density distribution. Viewing targets (VT) can be used to obtain a qualitative 2D image of the beam profile [5]. For quantitative measurement of spatially resolved 2D current density distributions a multiple Faraday cup array (FCA) is a versatile tool [6]. An in-situ comparison of VT and FCA performed at the EIS test setup in cooperation with L. Panitzsch (Institute for Experimental and Applied Physics, University of Kiel, Germany) could confirm good agreement. A detailed analysis of the data is in progress.

References


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Status of the EMittance Transfer EXperiment EMTEX * †

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In order to improve the injection efficiency of the round UNILAC heavy ion beam into the asymmetric acceptance of the SIS18 it would be of great advantage to reduce the horizontal emittance at the expense of increasing the vertical emittance by the so called emittance transfer [1]. As proof of principle a test set has been proposed with the ion optical layout described in [2]. The status of the proposed beam line at the transfer channel shown in Figure [1] is reported.

Experimental Setup

The EMTEX setup is situated in the existing TK beam line and consists of two quadrupole doublets, a split solenoid magnet with a foil stripper in the centre to prepare and magnetize the beam and three triplets including a skew triplet to administer the emittance transfer. The existing transfer channel beam line is not affected and may be used with the stored accelerator settings. While the two last triplets including the skew triplet are of old GSI possession and were refitted in our workshop, all other components had to be ordered newly.

Status of the subsystems

The two triplets including the skew triplet have been available in house and where overhauled by the magnet engineering division ENMA and the mechanic workshop CSTI of GSI. They are installed in the TK5 beam line [2], commissioned, and ready for use.

Figure 1: Setup for the emittance transfer experiment in the transfer channel TK (red), while the existing beam line (black) is not affected.

The solenoid magnet [3] has been designed by ENMA at GSI and manufactured at Danfysik. The vacuum chamber of the solenoid is a special design comprising a view port for on-line observation of the foil. For this reason the inside of the vacuum chamber had to be blackened to reduce reflections. Yet another special solution had to be developed by the GSI construction department for the connection box for the thick water cooled power cables. The solenoid with all components has been delivered, installed, and commissioned just in time.

Figure 2: The two existing, overhauled triplets installed in TK5. The first (left) triplet GTK5QT6 has been rotated by 45 degree to couple the x and y plane for the emittance transfer.

Figure 3: The solenoid installed in the beam line (left) and a schematic of the inner chamber and stripping foil arm (right).

Outlook

Unfortunately the delivery date for the quadrupoles has been delayed and they will be installed during the shutdown in May 2014. The first experimental run of EMTEX is scheduled for June 2014. In case of success it is foreseen to implement an emittance transfer setup in the HSI

References

A key projectile for the FAIR facility will be $^{238}$U. In routine operation of the GSI UNILAC, $^{238}$U is generated by a MEVVA ion source that delivers ions with comparably low charge states ($4^+$), which are accelerated to 1.4 MeV/u in the high current injector (HSI). The 1.4 MeV/u beam passes a region of high gas density, in which the charge is increased to $28^+$ by stripping of electrons. [1] Generally, higher intensities at charge states, preferably above $28^+$, are desirable. This would allow to operate the accelerator more reliably and efficiently.

To optimize the stripping efficiency and potentially increase the achieved ion charge states a program to upgrade the gas stripper has started. The modified stripper setup is depicted in Fig. 1. As a first modification, switching from the continuously fed supersonic $N_2$-jet to a pulsed gas injection, synchronized with the beam timing structure, has been implemented. This allows to increase the gas pressure inside the stripper chamber during a beam pulse, while still reducing the total gas flow. The gas injection was positioned inside a T-fitting, which was installed in the main stripper chamber to match the beamline. In a first test the pressure in the main stripping section as function of the opening time of the valve and the pressure along the beamline adjacent to the gas stripper section were measured.

![Diagram of the modified 1.4 MeV/u gas stripper](image)

Figure 1: Schematic view of the modified 1.4 MeV/u gas stripper as to be used for first measurements with a pulsed gas valve in beam experiments in 2014.

The gas pressure on the valve was 3 MPa. The dependency of the pressure inside the stripper chamber and the pumping performance on the valve opening time was evaluated for three different gases ($N_2$, Ar and He). These gases are planned to be investigated as potential stripper gases in the future, together with Xe.

The results of the pressure measurements near the gas outlet in the main stripper chamber (diaphragm vacuum gauge at P1, Fig. 1) are shown in Fig. 2. As the pressure varied according to the pulsed gas flow regime, only the maximum pressure values during one pulse are shown. Note that the vacuum gauge was placed at an entry point on top of the main stripper chamber, so the shown pressures do not represent the real pressure in the beamline. The pressure increases with increasing opening time and starts to level off at longer opening times. $N_2$ and Ar are pumped at about the same rate whereas He is pumped less efficiently. Therefore, the pressure at the vacuum gauge is higher for He at the same opening times. The measured pressure increases to values above 5 hPa, independent of which gas was used. The pressure in the adjacent beamline was also measured (vacuum gauges P2-P6, Fig. 1).

The optimum conditions with respect to the pressure in the main stripping region and the adjacent beamline as well as the experimental charge state distribution will be evaluated in beam experiments in 2014.

References


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Thermal Simulations of Thin Solid Carbon Foils for Charge Stripping of High Current Uranium Ion Beams at New GSI Heavy-Ion Linac

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This paper presents an extensive numerical study of heating of thin solid carbon foils by 1.4 MeV/u uranium ion beams to explore the possibility of using such a target as a charge stripper at the proposed new GSI high energy heavy-ion linac. These simulations have been carried out using a sophisticated 3D computer code that accounts for physical phenomena that are important in this problem. The stripper is assumed to be a thin circular foil of solid graphite with density 2.28 g/cm$^3$ and radius, $R_f = 1.5$ cm while the uranium beam is incident perpendicular to its surface. Three different foil thicknesses including 20, 30 and 40 μg/cm$^2$, have been considered.

In Fig. 1 we plot the temperature for 6 emA current at three different points along the foil radius, namely, $r = 0$ (center), 5 mm and 15 mm (outer boundary), respectively. It is seen that a maximum temperature of around 2200 K is achieved at the target center at the end of the pulse (100 μs), whereas the maximum temperature at $r = 5$ mm is about 1250 K. The temperature at the foil boundary, on the other hand, does not change. It is to be noted that although the sublimation temperature of carbon in air is much higher (3925 K), the target could be damaged due to the induced thermal stresses [1,2]. The corresponding temperature at the foil center in case of 30 and 40 μg/cm$^2$ is 2300 K and 2400 K, respectively. This is because diffusion of heat from the target center to the surface takes longer time that reduces the cooling rate.

In Fig. 2 we plot the same variables as in Fig. 1, but using 18 emA current. It is seen that the temperature at the foil center approaches the carbon sublimation temperature which means that it will not survive a single irradiation in this case. For 30 and 40 μg/cm$^2$ foil thickness, the maximum temperature is even higher. It is therefore concluded that use of a solid stripper foil is not feasible at the new high energy drift tube linac at GSI. Further details can be found in [3]

References

The Status of the High-Energy Linac Project at GSI

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The High-Energy (HE) Linac is proposed to substitute the existing UNILAC post-stripper section. Mainly the post-stripper consists of the Alvarez Linac, which is in operation over four decades successfully. The main parameters of the HE Linac follow the design parameters of the existing post-stripper [1], e.g. the HE Linac reaches the same output energy of 11.4 MeV/u at about half of the length. In comparison the beam pulse length and the pulse repetition rate is optimised to the FAIR requirements. The HE Linac will not provide with long duty cycle beams [2].

In the long term the substitution of the existing Alvarez is the only possibility to provide an adequate heavy ion injector for FAIR. The need for a future substitution is confirmed by a study recording the status of the existing post-stripper for investigating its future operating risk [3].

One important milestone for reducing the operating risk is the development of a new and modularised rf system, which is in progress [4]. The rf system can be applied to the existing Alvarez section as well as to the HE Linac in short pulse operation. Negotiations with commercial suppliers concerning the prototype of a high power amplifier are expected to be closed in spring 2014.

56 percent of the total costs are assignend to the rf systems (fig.1) according to the executive summary “Proposal for the HE Linac” [5], which was submitted in summer 2013 to the GSI supervisory board and the director’s board.

Outlook

In November 2013 the GSI accelerator chain for Uranium beam was reviewed. The review committee comprised five external and international recognised accelerator experts. As a result a window for the input beam parameters for the SIS18 is defined. For providing \( 2 \cdot 10^{11} \text{ } ^{28+}\text{U} \) particles a beam current of 15 mA at a pulse length of 80 \( \mu\text{s} \) within an emittance of 5 mm mrad is required for instance [6]. In addition a quasi Front-to-End simulation along the UNILAC shows, that by taking future upgrade options into account already, with the existing Alvarez section the Fair requirements are not reached [7]. Even by substituting the Alvarez section by the HE Linac the aim is not reached per se regarding the existing boundary conditions. Currently workpackages are designed together with the Institute of Applied Physics at Frankfurt University. Starting from the Ion sources to the SIS18 transfer channel every section is re-investigated for improvements in beam quality and intensity.

References

CUPID: New System for Scintillating Screen based Diagnostics

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Introduction

A new, fully FAIR-conformal system for standard scintillating screen based beam diagnostics was developed at GSI. To cover a wide range of foreseen applications, a new technical solution was required for diagnostics upgrade between the Experimental Storage Ring (ESR) and Cave A as a precursor to the upcoming FAIR High Energy Beam Transport lines. The newly developed system (Figure 1), including digital image acquisition, remote controllable optical system and mechanical design, was set up and commissioned without beam during the 2013 shut-down.

CUPID System Layout

CUPID (Control Unit for Profile and Image Data) is based on the Front-End Software Architecture (FESA) [1] to control beam diagnostic devices. The FESA class for the digital GigE camera (IDS uEye UI-5240SE-M, radiation resistant CMOS type) acquires the images and pre-processes the optical data as required by the geometry of the setup (rotation, stretching). It calculates the projections and the intensity histogram and converts pixel number into a position in millimeters, which results in absolute beam position and width. The performance of the system reached more than 15 frames per second with one connected client. To avoid network overload, the front-end computer processing the camera images is equipped with two network cards: one for the standard accelerator network and one for the direct connection to the GigE cameras via a local 10 GBit network switch. If desired, the raw image data can be written to a file for offline analysis. Additionally, dedicated FESA classes access industrial Programmable Logic Controllers (PLCs) for a reliable slow control solution. A Siemens PLC (main unit and satellites) handles control of lens focus and iris motors (LINOS MeVis-Cm 16), read and set by a PID controller (FM355C). PLC digital outputs (SM322) switch the LED to illuminate the P43 target (ProxiVision) for calibration issues. Camera control, timing, as well as power supply and reset options for up to eight digital cameras are realized by the in-house developed Camera Power Supply controller CPS8.

Operating Features

The use of the FESA framework results in a clear separation between the data acquisition part and the graphical user interface (GUI) part. CUPID includes two parts: a) data acquisition and control using FESA and b) Java based analysis and display tools (see Figure 2). In the main control room, the user can select and start the camera in free-run or triggered mode, adjust the camera and iris settings as required for commissioning, alignment and transversal beam profile measurements. The GUI client displays the processed image, the horizontal and vertical intensity profiles as well as the intensity histogram. The display is automatically updated whenever the FESA class delivers new image data. If only profiles are needed, the image display can be disabled to reduce network load. CUPID is the first fully digital, FAIR control system compliant readout of scintillating screens for beam diagnostics.

References


REMBRANDT – The REMote Beam instRumentation And Network Diagnosis Tool

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Introduction

At FAIR, all beam instrumentation devices and associated data acquisition components will be distributed and installed over a large and partially inaccessible radiation exposed area. Besides operation of the device itself, like acquisition of data, it is mandatory to control also the supporting LAN based components like VME/µTCA crates, front-end controllers (FEC), middle ware servers and more, to reduce trouble-shooting efforts and reaction times on DAQ system failures. Fortunately, many commercial systems provide means for remote control and monitoring using a variety of standardized protocols. REMBRANDT is a Java framework, which allows the authorized user to monitor and control remote systems while hiding the underlying protocols and connection information such as IP addresses, user-ids and passwords.

Architecture

REMBRANDT is based on a client-server architecture, which is shown in Figure 1. The clients as well as the server are fully implemented in Java. Thus, the same application can be started in the main control room (Linux X-terminals) and/or on the office PC (typically Microsoft Windows) and can be distributed via Java webstart.

The REMBRANDT server periodically queries all devices within several separate monitor threads typically every 10 seconds. It also logs changes in the device states into a database, send notifications by e-mail to maintainers, handles access control and provides a web server for read-only access to the device states and logs.

Several clients are available to the REMBRANDT user. Besides the main control and monitoring tool, clients for system information management, database and user administration are provided. All clients interact with the server exclusively by Remote Method Invocation (RMI), which is a proven standard mechanism within JAVA for procedure calls within a network. Thus, complex subscribe/publish procedures are avoided.

Currently, REMBRANDT supports the following protocols to control (switch on/off, regulate fan speed, etc.) and monitor different types of hardware: SNMP (Simple Network Management Protocol); iAMT (Intel Active Management Technology); IPMI (Intelligent Platform Management Interface); Ping; RDA (remote device access [1] for FESA [2] devices). REMBRANDT also provides direct terminal access to devices via telnet, ssh or iAMT SOL (Serial-Over-LAN). It hides the login information as well as the actual connection specifics, i.e. directly or via a terminal server. Besides obtaining a login shell this is mainly used to observe the device boot process for diagnostic purposes.

Outlook

REMBRANDT will significantly help to keep a status overview over the huge amount of expected BI DAQ and infrastructure systems at FAIR. It is currently in the test phase and already covers over 90% of the foreseen device types. Future development will focus on the scalability with a much larger number of devices and additional protocols like IPMI Serial-Over-LAN or evaluation of logfiles like syslog.

Furthermore, REMBRANDT should be considered as only one, albeit major, pillar in the global remote monitor and control concept for beam diagnostic devices. It is complemented by IP based KVM switches for VGA/USB equipped systems and PLC controlled power supply units of beam line installed DAQ components, such as digital cameras, to provide permanent access and full remote reset capability.

References


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Retrofitting of a non-invasive Bunch Shape Monitor for GSI LINACs

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Introduction

Within the FAIR-Project a proton LINAC [1] is scheduled as a new injector for the SIS18. A non-invasive Bunch Shape Monitor (BSM) is foreseen to determine the longitudinal bunch structure with a phase resolution of 1°, with respect to the 325 MHz acceleration frequency. It is intended to ensure proper longitudinal matching of the accelerating structures. The presented device is based on the creation of secondary electrons by the ion beam passing a section of high local nitrogen pressure. The secondary electrons are accelerated by an external driving potential towards a time-resolved imaging system to obtain the bunch time structure [2].

Compensation of Beam Deflection

The applied driving potential has unwanted effects on the ion beam. For an 11.4 MeV/u beam with an applied voltage of -31 kV the beam deflection goes up to 0.7 mrad (for protons) according to CST based calculations. For the present monitor location at the transfer channel a significant fraction of the beam is lost [3]. To overcome this flaw, two additional electrodes have been designed and build to fit in the existing vacuum chamber. To design an appropriate electrode geometry a field simulation was performed, using CST finite element code.

Figure 1: The upper image shows a CST simulation of the potential distribution at the symmetry plane along the beam axis. The lower image shows a calculation of the E-field along the beam axis.

Figure 2: Two compensation electrodes installed in front and behind of the original Field-Box, the red arrow indicates the beam path.

The most advanced design for optimal compensation is an additional Field-Box with the same geometry split in the middle into two and to put one in front and one behind the original Field-Box. Due to the lack of available insertion space inside the BSM vacuum chamber, this solution is not an option. A more sophisticated design based on CST simulations was chosen, which stays as close as possible with the optimal layout (see Fig. 1). Finally the selected design is a compromise of two contrary objectives, namely achieving a sufficiently homogeneous high field strength with a fixed voltage of -31 kV and leaving enough space in a symmetry axis coaxial to the beam axis, at least 55 mm in diameter (iris size in front of the BSM). This does forbid two capacitor plates with a fixed distance. For sufficient compensation the distance between the capacitor plates is below 40 mm which allows a maximum field strength of 620 V / mm in comparison to the Field-Box with 420 V / mm. In addition the capacitor plates are bended in the middle to allow the beam free pass within a 60 mm diameter (see Fig. 2).

The achieved compensation at 5 mm around the beam axis is about 99%, decreasing with distance to the axis. Within a 40 mm diameter the deflecting is still suppressed by 90%, which corresponds to a remaining deflection angle of 0.07 mrad.

Figure 2: Two compensation electrodes installed in front and behind of the original Field-Box, the red arrow indicates the beam path.

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Direct measurement of mechanical vibrations of the 4-rod RFQ at the HLI

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Abstract

Introduction

The high charge state injector HLI at the UNILAC was equipped with a new 4-rod Radio Frequency Quadrupole RFQ in 2009. It has been in operation since 2010 [1]. At higher rf amplitudes, strong modulations of the rf matching with \( f_{\text{mod}} \approx 500 \text{ Hz} \) were observed, limiting the pulse length and rf amplitude achievable. They are attributed to mechanical oscillations of the rods, excited by the rf pulse. As these modulations could only be seen during the rf pulse, a direct, independent observation of the mechanical vibrations was needed.

Measurements

A laser vibrometer was used to investigate any movement of the rods independent of rf operation. The vibrometer uses the interference of a laser reflected from the surface of interest with the original light to determine the velocity of the surface. By pointing the laser through a vacuum window onto e. g. the back edge of a rod, we were able to measure the vibration of the rods in situ for different operational states [2].

Results

Fig. 1 shows the effect of the rf pulses on the rods, measured with the vibrometer continuously running, i.e. without synchronization to the rf pulses. Without rf power only some minor vibrations below 100 Hz are visible, excited by cooling water, pumps etc. With rf on, a strong line emerges at 500 Hz. For the inset, only data between the rf pulses were analysed. The spectrum shows the 500 Hz signal and a dominant feature at \( \approx 350 \text{ Hz} \). We attribute these lines to different vibrational modes of the rod, with only the 500 Hz mode affecting the rf. Fig. 2 shows the amplitude of the vibration at 500 Hz for different pulse lengths at 50 Hz pulse repetition rate, according to standard operation. The periodic behaviour of the amplitude is consistent with operational experience, especially the minima indicate pulse lengths where operation of the RFQ is most stable. The periodicity of 2 ms matches the vibration frequency of 500 Hz. Together with the small linewidth corresponding to a decay time of 0.3 s (Fig. 1), this confirms the interference of sequentially excited vibrations, which cancel out during the rf pulse at certain pulse lengths [1].

Outlook

Mechanical and rf simulations of the present RFQ structure will be conducted to understand the vibration modes and their effect on the rf properties. Based on this, new electrodes will be designed to mitigate these effects.

References

[2] We appreciate the extensive help and assistance of Kay–Obbe Voss, who also provided the laser vibrometer and other equipment.

Figure 1: Frequency spectrum of the vibration velocity of the RFQ rod with rf off (dotted, 10 times magnified) and with rf pulses at 50 Hz pulse repetition rate (solid). Inset: Frequency spectrum of the free decay of the oscillations between the rf pulses at 1 Hz pulse repetition rate.

Figure 2: Velocity of the mechanical vibration as a function of the rf pulse length at 50 Hz pulse repetition rate.
Calculation of the quadrupole moment $\sigma_x^2 - \sigma_y^2$ for an asymmetrical Pick-up

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Introduction

This report presents the simulation results for an asymmetric pick-up installed at GSI SIS-18. The pick-up is planned to be used as transverse beam size oscillations monitor at SIS-18, and possibly as a transverse emittance monitor [1] in future. The properties of the pick-up are studied in order to evaluate its usage as a quadrupole moment monitor. Further, a comparison of signal processing methods such as traditional difference over sum, log-ratio and modified log-ratio [2] with respect to the suppression of beam position contribution in the quadrupole moment $\sigma_x^2 - \sigma_y^2$ is presented.

Simulations and Results

Quadrupole signal for a centred beam

Assuming that the beam is long compared to the pick-up electrode, the pick-up properties are determined electrostatically with the simulation software CST EM Studio (Electrostatics solver). The quadrupolar signal $\Xi$ for traditional diff-over-sum method is defined as $(R + L - T - B)/(R + L + T + B)$ where $R, L, T$ and $B$ are the voltages induced on the respective pick-up plates. It is calculated for a range of quadrupole moment such that transverse horizontal beam radius $\sigma_x$ is varied from 7.5 mm to 50 mm while vertical beam radius $\sigma_y$ is 7.5 mm.

**Figure 1:** Left: front view of the pick-up design; right: quadrupole signal $\Xi$ using the diff over sum method; $\sigma_y/b = 0.075, 0.075 \leq \sigma_x/b \leq 0.5, \Xi = \Xi_0 = 0, b = 100.3$ mm, $a = 35.3$ mm.

Figure 1 shows that the quadrupole signal is not linear in the whole range of the beam dimension used for the simulation. However, in the range covering typical SIS-18 beam dimensions, i.e. $0 \leq (\sigma_x^2 - \sigma_y^2)/b^2 \leq 0.05$, the curve fits well with a straight line (linear regression with the coefficient of determination $R^2 = 0.9997$), as shown by dotted line in Fig. 1. The slope $m$ and the zero point $(\sigma_x^2 - \sigma_y^2)_0$ of the fitted line are 0.678 and 0.4593, respectively.

**Effect of the beam position ($\Sigma, \Sigma_0$)**

Now, taking into account the beam position in the quadrupole signal, the beam dimension can be obtained simply by Eq. (1).

$$\frac{\sigma_x^2 - \sigma_y^2}{b^2} = \frac{\Xi}{m} + \frac{(\sigma_x^2 - \sigma_y^2)_0 - n}{b^2}$$

**Figure 2:** Relative error of the pick-up values of $(\sigma_x^2 - \sigma_y^2)$ at $\Sigma/b = 0.075, \Sigma_0/b = 0.05; b = 100.3$ mm

In Fig. 2, the relative errors in the calculated quadrupole moment for a variation of $\sigma_x$ in the range of 7.5 mm to 22.5 mm with a constant $\sigma_y = 7.5$ mm and beam position ($\Sigma = 7.5$ mm, $\Sigma_0 = 5$ mm) using different processing methods are shown.

Conclusions

In the beam size range of interest, the quadrupole signal calculated using the asymmetric pick-up is found to have a linear dependence on quadrupole moment for a centred beam. The dependence of quadrupole moment on beam position is studied by three signal processing methods. The modified log-ratio method shows the least influence of beam position on the quadrupole moment.

References


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Progress of the 325 MHz sc CH Cavity *

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Abstract

At the Institute for Applied Physics (IAP), Frankfurt University, a superconducting 325 MHz CH-Cavity has been designed and built. The 7-cell cavity features a geometrical $\beta$ of 0.16, corresponding to a beam energy of 11.4 AMeV. The design gradient is 5 MV/m. Main novel features of this resonator are a compact design, low peak fields, easy surface processing and power coupling. Furthermore a new tuning system based on bellow tuners inside the resonator will control the frequency during operation. The progress in processing the cavity as well as tuner drive measurements are presented.

Progress and Setbacks

After successful measurements [1] at Frankfurt the cavity was sent back to Research Instruments for final processing steps. Buffered Chemical Polishing and High Pressure Rinsing (s. fig. 1) have been performed.

Figure 1: Set-up for BCP (left), Mounting for HPR (right).

Afterwards a helium leak was found in the area of the pick-up pipe socket which led to a reaming of the pick-up pipe (s. fig.2). The subsequent reparation steps have been performed and the processing steps can be repeated.

Figure 2: Helium leak at the pick-up pipe (left), Reamed pick-up pipe (right).

Tuner Measurements

The new dynamic frequency tuner for sc CH-Cavities consisting of a stepper motor and a fast piezo actuator provides slow and fast tuning by pushing/pulling capacitive acting dynamic bellow tuners, which are welded on the girders inside the cavity. The slow tuners must be able to deflect the bellow tuner around +/- 1 mm, which corresponds to a tuning range of several hundred kHz to compensate frequency changes due to evacuation and cavity cool down. Additionally, fast piezo actuators react on frequency variations in the range of several hundred Hz caused by dynamic effects like Lorentz-Force detuning or microphonics. A prototype of this frequency tuning system was built at the workshop of the IAP. First measurements at room-temperature have been performed.

Figure 3: First tuner measurement results at room temperature.

Figure 4: Mounting of the fast tuner system on the helium vessel (left). Main components of the tuner system (right).

References


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Controlled beam loss experiment at SIS18

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The FAIR beam loss monitoring (BLM) system is based on different types of particle detectors. Its main purpose is the minimisation of beam losses around the SIS100 synchrotron and protection of machine components from unnecessary activation. As a part of a BLM feasibility study an experiment with controlled losses on a scraper was performed at SIS18 section.

The aim of this study is the production of beam losses at a well defined position and the measurement of the shower intensity with BLM detectors. In the present setup two plastic scintillators of the existing BLM system were used. They are installed downstream of a scraper at a distance of 2 and 5 meters, respectively. The scraper was positioned close to the beam orbit. Uranium beams of different energies and intensities in the range of 100-900 MeV/u and 10⁸-10⁹ particles were utilized. The beam was injected into the SIS18 synchrotron, accelerated and then stored for several seconds. During that time the beam was excited and was slowly impinging on the scraper. The resulting count rates in the scintillators were monitored through the ABLASS data acquisition system[1] and further analysed with a ROOT code[2]. Figure 1 shows one BLM signal (blue curve) and the DC current transformer signal DCT (black curve) in arbitrary units. In the flattop region no significant BLM signal is detected. After 2 seconds the exciter was turned on and produced the shown BLM signal. It was carefully checked that no significant losses were produced at other locations around the synchrotron.

During the initial storage when the exciter is switched off only a small fraction of the beam is lost. In order to determine the beam life time (see red curve in figure 1) the beam current can be approximated by an exponential function. When the beam exciter is switched on, one can calculate the number of lost particles on the scraper for each time-bin by taking the difference between the extrapolated life time function and the actual number of particles measured by the DCT.

For each energy, the data were approximated by a linear fit and the ratio between BLM signal and loss rate was retrieved. One can interpret this ratio as a normalised shower intensity. This dependency between the ratio and the beam energy is shown in Figure 2. At low energies it seems to follow parabolic curve. Starting from 300 MeV/u the shower strength of the beam losses follows the expected linear trend which one expects from the results of Monte Carlo simulations. The experiment will be repeated with LHC type ionisation chambers[3] which will be installed during the next short shutdown in order to measure their response function and estimate their signal strength for possible SIS100 beam loss scenarios.

Figure 1: Measured signals of DCT and scintillator in a.u.

Figure 2: BLM signal to loss rate ratio in dependence on beam energy

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Beam Phase Feedback for Dual-Harmonic Operation of RF Cavity Systems

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Introduction

After completion of the FAIR Project, the SIS 18 will be used as pre-accelerator for the SIS 100/300 and its cavities will be run in dual-harmonic bunch lengthening mode (BLM). To damp longitudinal rigid dipole oscillations a phase feedback system is used [2] which was so far only tested for the single harmonic mode. The beam phase signal with respect to the group DDS (Direct Digital Synthesizer) signal driving the cavities is filtered by an FIR (Finite Impulse Response) filter and fed back to the group DDS. On November 21st 2012 a beam experiment was carried out showing that dipole oscillations can be damped using an FIR filter also in the dual-harmonic mode. Some of the results were already presented in [1, 3].

Control Loop

An overview of the feedback loop is given in Fig. 1. Electrical (analog or digital) signals are indicated by a black arrow and optical signals by a dashed red arrow.

![Figure 1: Beam phase feedback loop](image)

To each gap voltage an additional phase shift $\varphi$ (respectively $2\varphi$) can be applied by means of an input voltage at the CEL (Calibration Electronics Modules) using an AWG (Arbitrary Waveform Generator). This is used to excite dipole oscillations on flattop while the basic frequency (and amplitude for acceleration) is supplied by the central control system. Both cavities synchronize with a group DDS signal whose phase can be changed by the splitter, doubling the desired phase shift $\varphi_{\text{gap,d}}$ at its input for the second harmonic ($h = 8$) cavity. Beam phase control is realized in the DSP (Digital Signal Processor) denoted as 'DSP BPC'. It consists of a phase detector, a digital filter, an integrator and a gain K as can be seen in Fig. 2. The beam current $I_{\text{beam}}$ is measured with an FCT (Fast Current Transformer). The FOH ( Fibre Optic Hub) transmits data between DSP, CEL and DDS of each cavity.

![Figure 2: Block diagram of BPC DSP algorithm](image)

The controller feeds back the phase difference $\varphi_{\text{det}} = \varphi_{\text{B}} - \varphi_{\text{gap,d}}$ (with $\varphi_{\text{B}}$: phase of bunch barycenter and $\varphi_{\text{gap,d}}$: desired cavity phase shift for $h = 4$), filtered by the FIR filter [2]

$$H_F(z) = \frac{-\frac{1}{4} + \frac{1}{2}z^{-1/(2T_{\text{fpass}})} - \frac{1}{4}z^{-1/T_{\text{fpass}}}}{z^{-2}},$$

(1)

where $f_{\text{pass}}$ is the passband center frequency of the filter. The bunches were rigidly displaced by $\varphi_{\text{B}}(t_0) = 20^\circ$ at a flattop energy of $E_{\text{kin}} = 120$ MeV/u, representing a test scenario in which a dipole oscillation with a defined amplitude is excited. Fig. 3 shows a dipole oscillation in closed and open loop. The additional damping is clearly visible.

![Figure 3: Measurement of dipole oscillation damping](image)

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Measurement of the magnetic properties of the Ferroxcube 8C12m material∗

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Introduction

The accelerating cavities which are operated in the GSI SIS 18 synchrotron for the acceleration of heavy ions at harmonic number 4 are filled with Ferroxcube 8C12m ferrite material. The characteristics of such materials depend on a variety of parameters, notably the external bias magnetic field. This distinctive feature is used for tuning of the resonance frequency of the cavity according to the revolution frequency of the heavy ions. Evidently, for a better understanding of the tuning process, the knowledge of relevant material characteristics is inevitable. To this end, experiments were carried out at the GSI facility with the aim of determining the dependence of the complex permeability of the Ferroxcube 8C12m material both on the frequency and on the bias magnetic field strength.

Measurement setup

The basic measurement setup is as follows. Two ferrite ring cores equivalent to the ones actually installed in the SIS 18 cavity are mounted inside a copper cavity (cf. Fig. 1). The toroids can be biased via 105 crossed current windings with the help of the direct current $I_{bias}$. Moreover, the necessary alternating components are coupled to the device under test via one additional circuit, which consists of a centric wire and the cavity housing. This circuit is connected to a network analyzer (NWA) for the measurement of the input port voltage reflection coefficient, i.e. the $S_{11}$-parameter. For preparation of a defined remanence state, the bias current is driven to the maximum value for a short time.

Data analysis

After the measurements, the real and imaginary part of the admittance of the device are available as a function of frequency for different bias currents. The values of the permeability are then extracted as follows. Firstly, it is assumed that the system can be described by an equivalent circuit, whose admittance is given by

$$ Y = \frac{1}{R_0} + i\omega C_{dist} + \frac{1}{i\omega L_s + R_s}, $$

with the external resistance $R_0 = 50\,\Omega$, the distributed capacitance $C_{dist}$ and the inductance and resistance of the toroids in series representation $L_s$ and $R_s$, respectively. Whereas $C_{dist}$ is obtained from a separate measurement, it is possible to formulate analytical expressions for $L_s$ and $R_s$, which involve only geometric quantities and the complex permeability $\mu_s = \mu_s' - i\mu_s''$. Hence, by solving for the real and imaginary part of $\mu_s$, one can finally evaluate the complex permeability for each frequency point. The obtained values for two different bias magnetic field strengths are shown in figure 2.

Summary and outlook

The complex permeability of the Ferroxcube 8C12m material was obtained from measurement as a function of both frequency and bias magnetic field strength. A more detailed data analysis together with a discussion of the obtained results will be published in the near future.

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Figure 1: Schematic view of the measurement setup. Two ferrite ring cores with bias current windings are installed inside a cavity housing.

Figure 2: Real ($\mu_s'$) and imaginary part ($\mu_s''$) of the permeability as obtained from the data analysis for a bias magnetic field strength of 0 A/m and 4.6 kA/m (low RF-power values).
In this short report, we show the current status of the project Transverse Feedback System (TFS) for the SIS 18, which can be commissioned later at the SIS 100 of FAIR project, upon its completion.

The TFS features and parameters are designed to have a large dynamic range such that it can be installed at the SIS 18 as well as the SIS 100. Testing the functionality of the System on a real beam at the SIS 18 is planned in the next few months.

A new concept for using multiple pickups in estimating the feedback correction signal in order to minimize noise power has been addressed. Furthermore, a distributed system design and synchronization scheme considering the current BPM Liberias of the existing SIS 18 facility has been developed.

System Design

We apply a new approach for mitigating noise at the PUs using more than two PUs at different positions to estimate the feedback correction signal for the Kicker position.

Data acquisition for the TFS takes place at distinct devices – namely, the Liberias. Therefore, the system has to be realized in a distributed manner. The main subsystems of the distributed TFS are the Libera devices for data acquisition, and the central unit for calculation, intensive operations and synchronization.

In order to achieve the synchronization between the TFS central unit and the distributed Liberias, time stamps are transferred in addition to the position data from the Liberias to the central unit. These time stamps are calculated in terms of shared reference wavefronts among all the TFS nodes. Specifically, we use the RF signal as a shared reference in our design. A time stamp is composed of wave front number, and time shift from this wavefront. In addition to the reference signal, a trigger signal is needed to indicate the start of counting the wave fronts. Figure 1 shows the form of the synchronization signals.

![Figure 1: TFS synchronization signals.](image)

In order to stabilize head-tail oscillations and higher order modes, which become dangerous for high beam intensities, many position measurements and kicks must be achieved for every bunch. Therefore, a bunch-by-bunch system would not be enough here, and we implement a wide-band feedback system.

Feedback parameters, e.g., revolution frequency and linear combination factors, are provided via the GSI interface cards FG 380.221. System configuration is done by an external computer via Ethernet connection.

Implementation

The TFS central unit electronics are shown in Figure 2. The System is implemented on a Virtex 6 FPGA ML605 kit from the company Xilinx. Several daughter cards have been deployed in order to connect this kit to the Kicker, the FG 380.221 cards, and the Liberias.

![Figure 2: TFS board.](image)

The beam position data from the PUs are sampled and preprocessed at the Libera kits from the company Intrumentation Technology. The data as well as the time stamps are then sent from the Liberias to the TFS central unit via two long fiber optical cables using Aurora multi-Gigabit communication. Clusters of Liberias are considered to connect to multiple BPMs.

References


Observation and simulation of transverse BTFs of high energy bunched beams

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Transverse Beam Transfer Functions (BTFs) are widely used in synchrotrons and storage rings to determine machine and beam properties (for example tune, tune spread, error resonances). In the projected SIS100, BTFs can potentially be used to measure the tune spread during proton operation. The transverse BTF \( R(\omega) \) is the fraction of the complex beam response amplitude \( A_{\text{resp}}(\omega) \) and the excitation amplitude \( A_{\text{drive}}(\omega) \) at a excitation frequency \( \omega \).

\[
R(\omega) = \frac{A_{\text{resp}}(\omega)}{A_{\text{drive}}(\omega)} \tag{1}
\]

In simple cases the BTF can be calculated analytically. For instance in the presence of tune spread caused by chromaticity, the imaginary part of the BTF is proportional to the transverse tune distribution in the corresponding plane [1].

The situation becomes more complex when the particle tune depends on the transverse amplitude of the particle as in the case of a nonlinear transverse element such as space charge or nonlinear fields. One example is a so-called electron lens, wherein an electron beam of the same profile as the ion beam is guided in parallel to the ion beam [2]. By adjusting the electron beam current and shape, a nonlinear lens can be set up which can be used to reduce transverse tune spread due to space charge (as could be envisioned for SIS100) or the beam-beam effect (for the Relativistic Heavy Ion Collider (RHIC)). We show how BTFs can be used to diagnose the proper operation of such a device.

**Analytic calculation**

In absence of SIS100 we focused on the case of an electron lens like one recently installed at RHIC. We make the assumption we are in the limit of coasting beams which we justify by the synchrotron frequency of the order of magnitude of the measurement time for a BTF sample. The conditions in SIS100 for high energy proton operation are similar in terms of synchrotron frequency. We calculate the BTF in the presence of a nonlinear lens analytically following [3] and obtain the result:

\[
R_i(\omega) \propto \int_0^\infty \frac{1}{\omega - \omega_i} \left( J_x J_y \right) \frac{d\psi}{dJ_i} dJ_x dJ_y \tag{2}
\]

With \( J_x, J_y \) the particle amplitude in action-angle variables, \( \omega \) the frequency of the BTF, \( \omega_i \) the amplitude dependent tune of the particles in the \( i \) direction \( i \in \{x, y\} \) and \( \psi \) the density of particles in \( J_x, J_y \) space. The presence of the derivative of the phase space density makes the BTF sensitive to fluctuations in the phase space density. The presence of \( J_i \) means the contribution of the particles increases with their amplitude. Particle-in-cell (PIC) simulations agree with eq. 2. Unfortunately unlike in the aforementioned case of chromaticity for typical \( \psi \) and \( \omega_i \) we can only solve the integral in eq. 2 numerically. Thus, our best method for reconstruction of the tune distribution is fitting against eq. 2 for a known shape of \( \psi \) and \( \omega_i \).

After verifying the fit method in simulation [4] we validated the method in measurement with the beam-beam effect as a substitute for an electron lens in a machine experiment at RHIC. The interaction strength recovered by the fit was in agreement with the expectation from measurements of the beam current and the emittance. The result of a BTF measurement is shown in Fig. 1 together with the fit.

The agreement between analytic results, simulations and measurement gives confidence that a similar method can be used to directly diagnose space charge tune spread of top energy protons in SIS100. The analytic equations follow the same approach. In application to SIS100 we plan to use our simulation model of the BTF that we successfully applied to RHIC to investigate electron lenses as a possible cure for space charge in SIS100.

**References**


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The microwave ion source and the low energy beam transport section (LEBT) developed in a joint French-German collaboration (CEA/Saclay – GSI/Darmstadt) will serve as an injector for the compact proton LINAC for FAIR [1]. The microwave ion source is presented in Fig. 1. The ion source will be located on the platform with a potential of 100 kV inside the special cage (Faraday cage). This ion source operates in pulsed mode with a frequency of 2.45 GHz. RF power is provided by a magnetron (microwave generator) and injected into the plasma chamber. The plasma chamber has a length of 10 cm and the diameter of 9 cm.

The hydrogen gas is injected into the plasma chamber up to the pressure of $2.5 \times 10^{-3}$ Pa approximately. In order to increase the proton fraction the chamber is coated with two boron nitride discs. There are two coils with a magnetic field strength of 87.5 mT, which are used to confine the plasma. The “five electrodes” extraction system consists of a plasma electrode, puller electrode (50 kV), screening electrode (~ 5 kV) and two ground electrodes [2]. The plasma electrode has an aperture of 8 mm. This extraction system allows the formation of high brightness ion beams with energies up to 100 keV and full beam currents of maximum 130 mA. The duty cycle of the ion source is 4 Hz with a flat top pulse length of 0.2 ms. The requirement for a rise and fall time is in the range of 100 - 200 µs. During the long time operation the ion source has shown its reliability with stable operation conditions and high performance, such as low noise level and small beam fluctuations < 5 % and pulse-to-pulse repetition < 2.5 % based on statistical inquiries. The low energy beam transport section consists of two solenoids and a diagnostic chamber in between. The solenoids have a length of 3 cm and maximum magnetic field strength of 500 mT [3]. There are two magnetic steerers, which are integrated into the solenoids for adjusting the horizontal and vertical beam positions. The diagnostic chamber is equipped with a Wien filter, an iris, an Allison scanner, a SEM profile grid and a beam stopper. The total length of the compact LEBT from the plasma electrode up to the entrance flange of the RFQ is about 2.3 m. The commissioning of the proton injector at CEA/Saclay is planned for the beginning of 2015. During this time the measurements of the emittance, beam current, and determination of the beam fraction and stability of the ion source will be performed. For the measurement of the space charge compensation a modernized 4-grid analyzer will be used. The 4-grid analyzer mainly consists of 4 metal grids as shown in Fig. 2. The first grid on ground potential serves for preventing any disturbance within the probe and the plasma and also for reducing the plasma density. The second grid serves as an electron repelling grid to repel electrons from the plasma. The third grid slows the ions down to the point that only the ions with a higher kinetic energy can pass through the potential on the grid. The fourth grid is needed as a repeller for secondary electrons. For beam current measurements the Faraday cup will be used.

References

Mechanical Design for the p-LINAC BPMs Inter-tank Section

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Introduction

Four-fold button Beam Position Monitors (BPM) will be installed at 14 positions along the 30 m long FAIR p-LINAC [1,2,3]. At four locations, the BPM has to be integrated in the inter-tank section between the CCH and CH cavities within an evacuated housing. The mechanical design of these BPM-locations is most critical. The tight space allows 58 mm insertion length only between CH cavity and quadropole magnet walls. The mechanical design was adapted based on previous numerical simulations as well as the given inter-tank dimensions [4,5]. The device performance was optimized by simulations. Special attention is payed on reduction of the rf-noise at the BPM location as generated by cavity excitation.

BPM Mechanical Design

The BPM system has to cover a beam energy range from 3 MeV to 70 MeV. Moreover, different beam pipe apertures have to be considered (30 mm to 50 mm). A commercial 14 mm button pick-up produced by Kyocera [6] was chosen for this purpose. However, it has to be tested for a 50 Ω impedance matching, which can be influenced by the inner ceramics. The button sub-assembly unit composite a titanium electrode of 2 mm thickness connected to a SMA co-axial cable as shown in Fig. 1.

The centre of the BPM inter-tank section is only 48 mm apart from the upstream drift tube boundary. The BPM mechanical design was optimized to control the rf field propagation into the tube reaching to the BPM’s co-axial signal path [3,5]. The BPM (tube diameter of 30 mm) is connected to the CH entrance flange (20 mm) by a conical section with a length of 20 mm to reduce an rf pick-up signal to max. 5 mV [3]. This value is satisfactory compared to the signal voltage of ∼1 V for nominal beam current of 35 mA. The assembly of the BPM consists of four buttons, a housing and a flange as shown in Figures 1 and 2, respectively. The buttons are recessed 0.5 mm from the inner radius of the tube to protect the electrode from stray beam impingement. Since the BPM is located near quadrupole magnet, a non-magnetic design is mandatory. Therefore, the housing and the flange will be fabricated from 316LN stainless steel. The buttons will be welded inside housing and both will be joined with the flange at the final assembly.

Summary and Outlook

The first phase of CEA-GSI collaboration for the BPM system includes the design and fabrication of the first BPM prototype. Currently, a button-type BPM has been designed and is being fabricated. It will be used as a test device for the rf field propagation from the cavity to the BPM at GSI and for a dedicated test bench at CEA. The related results will be considered for the final design.

References


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Modifications in the HEBT System Layout

There were no changes in the ion optical layout since its last official transfer to the building planners in October 2012. However, currently a direct connection from SIS18 to the Collector Ring (CR) is considered without modifying the requirements for the building planning. For this the section TSN1 is modified in a way that the beam coming from SIS18 can be either injected straight into the end part of the Super-FRS ring branch (which is connected to the CR via the sections TFC1 and TCR1) or guided directly to the NESR as before (to avoid a collision with the Super-FRS cryo-supply this branch has to be lifted in this region by about 50cm-100cm compared to its original layout). Whereas the connection to the NESR is part of module 6 the currently discussed new connection to the CR via the Super-FRS would become part of module 0-3.

To fulfill the requirements for the beam halo at the CBM/HADES target, a halo collimation system has to be integrated in the compact beam line from SIS100 to the CBM cave. In a first step suitable positions from ion optical point of view with sufficient available installation space were determined in the sections T1C1 and T1C2. In the next step simulations taking into account the generation of secondary particles in the collimators will be performed. The concept for the positions of safety beam plugs in the HEBT system was revised in coordination with the radiation protection department. Appropriate interlock magnets were identified and first simulations of the expected radiation level in building H0719A (main supply building north) were performed for beam deposition in the safety beam plug D20 located in section T1X2 in K0923A.

The concept to use the SIS100 machine setup beam dump in the HEBT system in K0619A for emergency dumping of light ions and protons from SIS100 was discarded. The new concept is described in [1].

Technical System Design

A first contract on the production of 51 dipole magnets including supports and vacuum chambers (batch 1) was closed between FAIR and Efremov Institute (St. Petersburg, Russia) in Aug 2013 and between FAIR and Budker Institute (Novosibirsk, Russia) in Jan 2013. The detailed specifications of batch 2 (17 dipole, 102 quadrupole, 80 steering magnets) were brought into the EDMS release process in Jan 2014. The detailed specifications of batch 3 (5 dipole, 71 quadrupole, 12 steering magnets) are currently under preparation and supposed to be available in spring 2014. The delivery of two pre-series magnets of batch 1 and their vacuum chambers is expected for the end of 2014. However, the production order for the series will follow the current partitioning HEBT A/B/C (defined by the project lead FAIR@GSI) which does not directly correspond to batch 1-3. Nevertheless, changes of the production order, e.g. due to changes in prioritization by the project lead or in civil construction, are possible.

In Oct 2013 the detailed specifications for 7 HEBT quadrupole power converter types were released. Currently a first contract between FAIR, the indian shareholder BOSE institute (Kolkata) and the provider ECIL (Electronics Corporation of India Limited) is under preparation. This contract will contain all quadrupole power converters needed for the 18Tm beamlines of module 0-3.

The major part of the detailed specifications required for the day zero beam diagnostics for the HEBT system was released (7/14) or is currently under approval (4/14). The indian shareholder BOSE institute started the tendering process of the HEBT beam diagnostics vacuum chambers in Jan 2014.

Major efforts were taken to deliver further required information for the building planning. E.g. 3D models of the SIS100 machine setup dump in K0619A, of the draft of the support structure including service platforms in building H0705A, of the course of Halfen rails for mounting HEBT300 at the tunnel ceiling as well as of free installation space for cable trays in G0702A were prepared. The HEBT supply areas in L0516A had to be rearranged significantly to provide mandatory escape routes, space for assembly and disassembly on the injection and extraction ramp was worked out in an advanced design project between ENMI and the department of computer integrated design of the TU Darmstadt.

Furthermore much work was invested in project planning at the beginning of 2013. Twenty project plans including resources (personnel, budget) and three different timelines for HEBT A/B/C were established by the WPLs as well as three major milestone plans for HEBT A/B/C by the MPL.

References


Interdisciplinary development of a support structure for components in building H0705A - A challenge for systematic requirements engineering


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Building H0705A is a branching and crossing point for 8 beam lines in the planned FAIR facility. 2 beam lines are inclined. In addition several components of other beam lines have to be transported via this building to their final installation positions. One also has to take into account that the installation of support structures and components will take place according to project planning in two stages. Furthermore the consideration of the product life cycle takes a fundamental part of the definition of requirements for the support structure.

Figure 1: Top view of beam lines in building H0705A.

In a first step all involved departments, so called stakeholders, were identified. In a second step a team with members of magnet department, vacuum department, beam diagnostic department, assembly department, alignment department, power converter department, media supply department, digital mock-up (DMU) department and the responsible machine project leader (MPL) started with a global task analysis. The question had to be solved, what the task of the support structure is, and what this means in consideration of the two project stages and of the product life cycle of the components. The next step included the definition of parameters which influence the system. Not only technical aspects had to be taken into account but also already defined processes for installation and maintenance, as well as safety aspects like length of escape routes and earthquake safety are influencing items. This step was followed by a structural analysis. What areal, staff and organizational structures have to be considered? The analysis of given and demanded infrastructure of the building gives also boundary conditions for the development of the support structure. A main item in the requirement analysis was the definition of all tasks of the involved departments and the dependencies of and to other tasks. For supporting all functions an analysis of communication shows the flow of needed information [1].

After collection all items have to be classified:

- Functional requirements
- Technical requirements
- Requirements for use
- Quality requirements
- Requirements onto other components, e.g. infrastructure
- Contract and legal requirements [2]
- Requirements of the product life cycle

Due to this classification the specifications for the development, construction and installation of the support structure could be prepared. In addition a time schedule for installation tasks and a course of actions for maintenance purposes could be developed. The validation of results during the development process in reference to the defined and classified requirements helps to ensure that all demands of the stakeholders will be fulfilled at the end of the process.

Figure 2: Beam lines with support structure in building H0705A.

References


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Status of the Superconducting Magnets for FAIR∗

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Introduction

Within this paper we report shortly on all the many different activities of the group which now is mainly focused on procuring the magnets and associated systems for the FAIR project.

Superconducting Magnets

Rapidly cycling magnets for SIS100

Dipoles – production status and first tests  The First of Series (FOS) dipole has been delivered [1, 2, 3] and its testing has started. The magnetic field was measured during the first ramp up followed by a first training of the superconducting magnet with the second quench above nominal current and a current of 15.1 kA achieved.

In parallel the different findings and according actions have been discussed with the producer so that the SIS100 dipole magnet series can be produced swiftly as soon as the FOS SIS100 dipole has been qualified.

Quadrupole modules  The quadrupole modules house all superconducting magnets of the SIS100 along with the beam vacuum chambers, beam position monitors and cryo-collimators.

The design of the quadrupole magnet and all corrector magnets in the quadrupole modules is finalised toward manufacturing. As the first of the SIS100 corrector magnets, the chromaticity sextupole magnet, has been constructed in collaboration with JINR. The iron yoke had been already prepared in the framework of the BMBF-JINR research contract. The coil will be wound and assembled into the iron yoke in the first half of 2014 at JINR. The test of the magnet will then follow.

In parallel the design of the first of series quadrupole module (type 2.5, see also Fig. 1) has been detailed intensively including all integrated components: the magnets, the support system up to the high temperature superconducting current leads. The suspension rods, connecting the cold mass with the cryostat, were designed to achieve a stability of the beam axis of ±125 μm for the main quadrupoles and ±175 μm for the associated correctors [4]. The design was further checked and approved to be a pressure vessel compliant with European standards.

Magnets of the Super-FRS

Dipoles  A collaboration agreement was signed between GSI and CEA/Saclay concerning the procurement of the superconducting dipoles for the Super-FRS. Saclay will take over the design finalisation next to the technical follow up. FAIR will then tender these dipoles. A ready design is expected mid of 2014 together with a signed production contract in 2014.

Multiplets  The specifications of the multiplets of the Super-FRS have been finished and the tendering process was started by GSI. Offers arrived in December. Negotiations with the companies are now under way; a contract should be signed within the first half of 2014. A general

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Figure 1: CAD Model of the fully integrated SIS100 quadrupole doublet module, type 2.5, including local current leads located in the central service port.

An order was placed with Babcock Noell for detailing all further quadrupole modules (five arc types, two arc termination types and two straight section types) along with the modules for injection and extraction, which shall be completed beginning of 2015.

Rapidly cycling magnets for SIS300

Magnets with fields up to 4.5 T are needed for SIS300. A first model magnet of the fast ramped \( \cos \theta \), 4.5 T SIS300 magnets was developed and tested successfully in collaboration with INFN [5, 6]. It is now awaiting further tests and additional measurements at GSI. A second collared coil, with enhanced field quality and conductor performance [7] is under construction [8]. After successful manufacturing and testing of two prototype quadrupoles and a steering dipole for SIS300, the activities of IHEP (Protvino, Russia) concentrated on the development of wide aperture quadrupoles for FAIRs HEDgeHOB experiment.

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overview over the superconducting magnets of Super-FRS can be found in [9].

Planning for Testing

Prototype test facility activities

The upgrade of the prototype test facility for testing the SIS100 magnets, which has been started in 2012, was finalised by the instalment of the new power converter able to deliver 20 kA at 22 or 66 V next to the HTS current leads. The power converter was brought into operation and tested successfully with a dummy load followed by testing and commissioning the HTS current leads up to 14 kA DC and 17 kA for slow ramps.

Series test facility activities

The procurement of the large scale systems has been started last year and finished with tendering the two power converters. Offers have been received with a tender to be awarded soon. In parallel the refurbishment of the building, the fabrication of the cryogenic infrastructure and the procurement of the current leads has started.

SIS100 string test

A test string will be set up in the series test facility consisting of a dipole, quadrupole module and cryogenic supply components. Dedicated components are being specified with the assembly of the string foreseen in 2016. The string will provide information on the interplay of the components listed above next to training for the teams building and assembling the SIS100 machine.

Testing Super-FRS Magnets at CERN

The large scale Super-FRS magnets will be tested at CERN. The number of test benches (3), the area and layout of the test facility, have been defined and the measurement program has been evaluated. Based on these achievements the procurement of the infrastructure can start so that the test facility will be ready when the first of series magnets of the Super-FRS arrive.

Current Leads

Dedicated HTS current leads, required for testing the FOS dipole, were developed, procured and successfully tested. This successful test was a clear go for the series of current leads required for the series test facility and the SIS100 machine.

Additionally low current leads are required for the corrector magnets installed within the SIS100 quadrupole module which are based on a conduction cooled warm end and a HTS superconductor connecting them to the cold end. The design of these current leads was completed this year.

Electrical Systems and Magnet Protection

The existing quench detection setup was updated and tuned for testing and operating the HTS current leads and the SIS100 FOS dipole. Moreover the production of the new quench detection system for the dipole series test facility has started now. Further the protection schemes for the SIS100 dipole and quadrupole circuits have been optimised. A set of standard tests and alternative dry tests based on IEC 60851-5 were defined for testing the electrical insulation of superconducting wires.

Conclusion

The procurements of the different superconducting magnets required for FAIR along with the associated auxiliaries has been started. The telegraphic style of this paper reflects the many activities that are undertaken to realise the FAIR project within the given scope and schedule.

References

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Cryogenics for SIS100 Accelerator

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Introduction

The cryogenic system for the FAIR (Facility for Antiproton and Ion Research) superconducting (SC) SIS100 synchrotron (see Figure 1) can be divided into six sections. Each of these sections will be fed from a separate Feed Box (FB) which will supply liquid helium (LHe) for magnet, vacuum chamber and bus-bar cooling as well as gaseous helium (GHe) for thermal shield cooling. Each sixth of the ring consists of one cold arc and a straight warm section with normal conducting accelerating cavities. Yet the warm section still needs to include three SC quadrupole doublets. The design progress of the cryogenic system for the SIS100 is described in the following sections.

Figure 1: Schematic representation of SIS100 synchrotron showing six BPL sections.

Cryogenic System

By-pass Lines (BPLs) bypass each of the six straight warm sections of SIS100 to supply LHe and cold electrical connections to the SC quadrupole doublets within these sections. Each of the six by-pass sections is alternately equipped either with the FB or the End Box (EB) which intercepts the helium flow. The purpose of such an infrastructure is to be able to separate the ring into six sections which can be independently cooled down, warmed up and serviced. Detailed technical specification [1] concerning the BPL System was prepared and approved at GSI in 2013. Based on this, the in-kind contract was signed between FAIR and Wroclaw University of Technology (WUT). In conjunction with the cryogenic group CSCY, the WUT is currently preparing a complete technical solution of the proposed BPL System. Internal holding structure for both helium headers and bus-bars is being designed as well as new clamping solution to fix the bus-bar pairs. The most complicated components namely the connection boxes that interface BPL to quadrupole units and on both sides to the cold arcs are also being engineered. The WUT will manufacture all the components of the BPL sections according to specifications until the end of 2016.

During 2014 all technical specifications of all remaining cryogenic components for SIS100 namely the FBs, Current Lead Boxes (CLBs), Feed-in Lines (FILs) and Feed-in Boxes (FIBs) together with all the interfaces will be specified. These components will also be produced within the in-kind collaboration with WUT. First-of-series components delivered to GSI will be tested within the Serial Test Facility (STF) currently under construction. The test of the SIS100 "Mini String" (MS) will provide the opportunity to assemble and test a small scale model of SIS100 cryogenic infrastructure. It will be composed of two SC magnets representing the cold arc section joined with the small part of the BPL section. This MS will be fed from the FB joined together with the CLB to supply LHe and two pairs of cooled SC bus-bars for both magnets. The FB in question will be supplied using STF cold box manufactured by Linde Cryotechnik. The control system for the MS has to be also developed at GSI based on UNICOS platform.

Serial Test Facility for SC Magnets

In order to test the fast-ramped SC magnets for FAIR, a cryogenic test facility is designed and currently under construction at GSI. The overall capacity of the cryo plant is 1.5 kW @ 4.4 K equivalent and can be distributed to four test benches individually. In total 108 dipoles for the SIS100 will be tested at cold. The capacity of the cryogenic system is designed in a way, that one magnet can be cooled down and another magnet can be kept at cold for the measurements in the same time. The other two test benches serve for warming up and for magnet exchange, respectively. Beyond the dipoles, the high flexibility of the set-up allows also the testing of other FAIR magnets, like the SIS100 quadrupole modules or the operation of a string configuration.

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Cryogenic Tests of Ceramic Feedthroughs for SIS100 BPM
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Introduction

Due to the cryogenic environment in which the Beam Position Monitors (BPMs) will be used at SIS100 synchrotron special attention has to be turned to the BPMs’ signal feed-throughs (FT) [1]. Present design considers titanium based, N-Type FTs isolated with Al\textsubscript{2}O\textsubscript{3} ceramics and welded into CF-16 flange. In a temperature range between room temperature and 4.2 K the requirements for the FTs are threefold: \textit{i}) high mechanical stability, \textit{ii}) vacuum-tightness even after many cold-warm cycles, \textit{iii}) good and stable electrical connectivity. These features were tested in 10 cold-warm cycles in the temperature range given above.

Methods and Results

Fig. 1 shows the test setup: Five N-type (FT) were mounted to a sixfold CF-16 crosspiece that was installed in a bath cryostat having a volume of 30 l. The free flange of the crosspiece was connected via a long stainless-steel pipe to a He leakage detector installed close to the cryostat. All M4 bolts (A4-80 stainless-steel) used at the flanges were fastened with a final torque of 2.6 Nm. One pair of spatially opposing FTs was electrically connected inside the crosspiece via a titanium rod equipped with spring contacts typically used in banana-connectors. This formed a 50 \textOmega transmission line with an intended impedance mismatch in the crosspiece center. The electrical connection between the two interconnected FTs and a Network Analyzer (NWA) was done by semiflex Tensolite coaxial cables. The quality of the electrical connectivity was measured using Time Domain Reflectometry (TDR) based on the analysis of the synthetic time domain signals measured by means of NWA [2]. Temperature monitoring was done by four resistive temperature sensors depicted in Fig. 1 by red boxes. The cryostat was equipped with a 25 \textOmega resistive heater for removing residual LN\textsubscript{2} left over from pre-cooling. A Nichrome heating wire wound around the crosspiece was used to accelerate cold-warm cycling so that the average duration of a cycle could be reduced to less than 2 h. He leak rate monitoring was performed during the whole test. Since the crosspiece was immersed into LHe any leaks at the FT that could possibly occur should be immediately registered in the leakage detector. TDR measurements were done first at room temperature and have been repeated after LHe was filled into the cryostat to cool down the crosspiece to 4.2 K. Fig. 2 compares two TDR measurements made at 299 K and 4.2 K in one of the 10 cold-warm cycles. The characteristic points (1), (2) and (3) on the plot correspond to the electrical connections within the crosspiece-FT unit. In the crosspiece-FT region both TDR signals are highly congruent which proves that electrical connections between rod and FTs do not change with temperature. Moreover, this connection is even better if compared to the left and right part of the plot, where the cryogenic cables’ passage between the outside and the inside of the cryostat is strongly effected by the temperature changes. Thus, it can be stated that the solution proposed here results in a stable and reproducible electrical connectivity under cryogenic conditions. Comparing Fig. 2 to the measurements made in the remnant cycles, the pointwise deviations of the impedance curves are below ±0.05 \textOmega in the significant region of the crosspiece-FT unit. Furthermore, within ten cold-warm cycles, the crosspiece-FT unit did not exhibit any leaks maintaining a He leak rate in the order of $5 \times 10^{-10}$ mbar·l/s. However, a slight loosening tendency of about 11% of the initial torque was measured at the bolts used for flange mounting. The usage of foldable washers might be necessary.

References

[2] see e.g. www.home.agilent.com, Application Note 1287-12

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Design of a Mutual Inductance Based Quench Detector for the Corrector Magnets of the SIS100

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The corrector magnets of the SIS100 employ a multi-strand superconducting wire known as Nuclotron [1] which is made out of up to 28 insulated strands rolled in parallel along a CuNi tube filled with liquid Helium. Due to this special construction of the Nuclotron cable, resistive bridge-based quench detectors will not be able to detect a symmetric quench (quench occurring at the same time in two or more strands) in these magnets. A novel quench detector based on the mutual inductance effect was developed in order to be able to detect all quench situations in the corrector magnets of SIS100.

Mutual Inductance Concept

The detectors based on this concept monitor two voltages: one is the voltage across the magnet and the other is the induced voltage in a secondary coil formed by one of the superconducting strands (see Figure 1).

Figure 1: Diagram of the magnet and the acquired signals for the mutual inductance quench detection. $V_{SM}$: voltage across a single magnet coil, $V_{MI}$: voltage across the mutual inductance coil and M: Mutual inductance coefficient.

If we define $V_{TH}$ as the quench detection threshold, we can have two conditions:

- a) $V_Q \leq V_{TH}$: the coil is in superconducting state, $R_Q \approx 0\Omega$.
- b) $V_Q \geq V_{TH}$: the coil quenches, $R_Q$ will rise and the quench protection system should be activated.

Mutual Inductance Quench Detector

A mutual inductance quench (MIQ) detector based on galvanic analog isolation barrier has been developed. This detector has been successfully tested in the lab with signal generators simulating the theoretical signals of the magnet during normal operating and quench conditions.

Figure 2: First version of the MIQ detector.

Outlook

After acquiring the signals (ramp up voltages, mutual inductance voltage...) of a real magnet (delivery expected on Q2-2014) and checking that the parameters (mutual inductance, impedances...) assumed during the development of this detector are correct, a second version of the detector with the following features is foreseen:

- Adjustment of quench detection parameters to the real SIS-100 magnets.
- Remote display of signals and voltages and remote control of all quench detector variables: signal processing parameters, thresholds, timing...
- Digital isolation based detector.

References

Estimation of beam induced heat load in SIS100 kicker magnets

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Introduction

In the operation of synchrotrons with high intensity beams electromagnetic parasitic loss causes heating of components. Especially the recent incidences at the LHC [1] gave rise to investigate this phenomenon for SIS100. The components most susceptible to beam induced heat load in SIS100 are the kicker magnets. Their ferrite yokes are strongly lossy especially at higher frequencies.

Heat Load Computation

The total beam induced heat power can be calculated from the longitudinal coupling impedance (CI) and the beam power spectrum. Since the CI is broadband for those lossy components, the effects of different bunches are uncorrelated and therefore the total power is linear in the number of bunches. Nonetheless, the charge and the number of particles per bunch enters squared:

\[ P = \frac{1}{2\pi} \sigma_t^2 N_{ppb} \omega_0^2 \sum_{k=-\infty}^{\infty} e^{-\sigma_t^2 k^2 \omega_0^2} \text{Re}\{Z_0(k\omega_0)\} \quad (1) \]

Here, \( \omega_0/2\pi \) is the revolution frequency and \( \sigma_t \) is the RMS length of a Gaussian bunch. Subsequently, the scenario with the highest heat load in SIS100 is the high intensity (\( 2e13 \)) single proton bunch at top energy with \( \sigma_t = 12.5n s \). The power in Eq. 1 is the instantaneous one. For the computation of temperature it has to be averaged over a SIS100 cycle. The crucial quantity in Eq. 1 is the CI. For structures like the kickers it can only be obtained numerically [2] or by bench measurements.

Impedance Computation

The heat load for a SIS100 (to SIS300) transfer kicker magnet has been investigated exemplary, since it might also be operated in a (Nitrogen-) cryogenic environment.

The CI is determined numerically by a code explained in [2]. A 2D approach is used, which means that a slice of the 3D model is taken and end-effects are neglected. Further the beam is assumed to be ultra-relativistic. The ferrite yoke consists of the material Ferroxcube 8C11 [3] which is a soft ferrite with dispersive complex permeability.

As visible in Fig. 1 the longitudinal CI has been investigated for two magnet gap configurations. The resulting power is 7kW for an open gap and 48W if it is filled by a copper sheet. Note that these values are worst case steady state, i.e. they have to be weighted by the SIS100 cycle. If the copper sheets are used, skew cutaways as in SIS18 kickers are not necessary.

Cooling and Temperature Equilibria

The heat conduction of Ferrite is quite good (\( \lambda_{\text{Ferrite}} \approx 4 \ \text{WK}^{-1} \text{m}^{-1} \)) which allows to calculate a temperature of the ferrite independent of the position. Nonetheless, the thermal conduction off the ferrite is very poor since there is a small vacuum layer between the ferrite and its stand. Therefore the thermal interaction of the ferrite with its surrounding is dominated by radiation. From the Stefan-Boltzmann law one finds

\[ T^4 = T_{rad}^4 + T_0^4 \approx \begin{cases} T_{rad}^4 & \text{if } T_{rad} \gg T_0 \\ T_0^4 & \text{if } T_{rad} \ll T_0 \end{cases} \quad (2) \]

\[ T_{rad} = \sqrt[4]{\frac{P}{\sigma_{SB} C L K_z}} \approx 200K \quad \text{for } P = 50W, \quad (3) \]

where the outer circumference is \( C = 0.86m \), \( L = 0.8m \) and the average emissivity is assumed as \( K_z \approx 0.8 \). Therefore cryogenic kickers are always at radiation temperature and warm kickers stay at room temperature for heat power below roughly 250W. This means that the impedance and heat load values for the improved design (with copper sheets) are acceptable.

References


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Halo collimation of fully-stripped light and heavy ions in the SIS100

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Introduction

The FAIR synchrotron SIS100 will be operated with high-intensity proton and ion beams [1]. The collimation system should prevent beam loss induced degradation of the vacuum, activation of the accelerator structure and magnet quenches. A conventional two-stage betatron collimation system is considered for the operation with protons and fully-stripped ions [2]. We propose to use 1 mm thick tungsten foil as the first stage – primary collimator (scatterer) and two 400 mm blocks at as the second stage – secondary collimators (absorbers).

Interaction of heavy ions with collimators

For collimation studies we are interested in angular scattering, momentum losses and fragmentation of ions in the collimator material. A charged particle passing matter experiences multiple Coulomb scattering. According to Moliere theory, the angular distribution of scattered particles is roughly Gaussian with the r.m.s. angle \( \theta_0 \) (Eq.1), \( B\rho \) is the magnetic rigidity and \( x \) is the foil thickness.

\[
\theta_0 = \frac{0.47}{\beta(B\rho)[Tm]} \left[ \frac{x}{X_0} \left( 1 + 0.038 \ln \left( \frac{x}{X_0} \right) \right) \right], \quad (1)
\]

here \( X_0 \) is radiation length, tabular value for tungsten is \( X_0 = 3.504 mm \). Moliere theory predicts a Gaussian distribution in the range \( 10^{-3} < x/X_0 < 100 \).

Momentum loss is described by (Eq. 2) with the corrections to standard Bethe-Bloch term \( L_0 \). The \( \delta L_{shell} \) correction represents the motion of electrons in the matter, \( \delta L_{Bark} \) is proportional to \( Z^3 \) and \( \delta L_{LS} \) takes into account the finite radii of heavy nuclei [3].

\[
-\frac{\delta p}{p} = \frac{K Z_i}{\beta^4 A_t} \left[ L_0 + \delta L_{shell} + \delta L_{Bark} + \delta L_{LS} \right], \quad (2)
\]

here \( K = 3.07 \cdot 10^{-4} GeV g^{-1} cm^2 \). According to [3], the momentum straggling has a Gaussian distribution for ions heavier than \( 40Ar^{18+} \) at SIS100 injection energy.

Cross-sections and, hence, probabilities of the inelastic nuclear interaction for light and heavy ions passing through the tungsten foil were calculated using Tripathi formula [4]. The overall probability of fragmentation for \( 238U^{92+} \) ions in our application is 6% and lower for lighter ions.

Simulation studies of cleaning efficiency

The simulation tool for cleaning efficiency studies uses an initial distribution of \( 10^5 \) halo particles and simulates their interaction with a collimator using implementation of models described above (Eqs. 1, 2). Then particles are tracked in the accelerator lattice with aperture limitations using MADX. After each consecutive turn, all particles are checked for impact on the primary collimator. In case of an impact, particle-material interaction is calculated.

A large portion of the halo particles is lost during the first pass through the collimation system (singlepass cleaning), however, high efficiency is gained after many turns (multipass cleaning), see Fig. 1.

![Figure 1: Cleaning efficiency at the injection energy for light and heavy ions.](image)

The cleaning efficiency decreases with the mass number due to increasing momentum losses in the primary collimator. Strongly off-momentum heavy particles are unable to make one turn in the accelerator and are lost in the high-dispersion region of the lattice.

References

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Measurement of the behaviour of residual gas particles on cryogenic surfaces to improve the simulation of dynamic vacuum effects

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Introduction

The dynamic vacuum refers to pressure rises occurring during beam operation in particle accelerators. It is caused by lost beam ions triggering stimulated desorption of gas particles from the walls which may cause even more beam loss. This has to be compensated by pumps as fast as possible to prevent a self-amplifying effect.

To achieve this, the cryogenic vacuum chambers of the SIS100 will act as surface pumps. They are able to pump gases according to their vapor pressure curves which are sufficiently low for stable beam operation for most gases. This is called cryocondensation. An important exception is hydrogen. Fortunately, it can be pumped to lower pressures by so called cryosorption if the surface coverage of the cold walls is sufficiently low [1]. This effect can be characterized by two parameters: The sticking coefficient describes the probability of a gas particle impacting on the surface to be bound. It is directly linked to the pumping speed provided by the cryogenic walls. The mean sojourn time describes how long a particle remains bound to a surface. Both parameters together determine the equilibrium pressure. Once known they will be used to improve the quality of simulation of the StrahlSim [2] code.

Measurement of the parameters

An UHV experiment (Figure 1) to determine these parameters is currently set up. The cold surface that will be tested is provided in the form of a small chamber which is cooled by a cold head. The target temperature range is 5 to 20 K. The measurement will be divided in two phases: At first, the pumping speed of the chamber is quantified at different temperatures and surface coverages to get the sticking coefficient. In the second phase, the corresponding equilibrium pressure is evaluated, which yields the sojourn time.

To link the pressure values measured by the gauges to the desired parameters, the simulation code MolFlow+ [3] is used to perform a data inversion. An alternative method for interpretation of the data is the calculation of unknown vacuum properties like the pumping speed and the outgassing rate from known or measured properties like the pressures and the conductances. The VakDyn [4] equations, which are also the basis for the vacuum simulation in StrahlSim, provide a set of linear equations for this purpose. Simulations showed, that the warm part can be represented by two isobaric vacuum elements, but the cwt shows a continuous drop in pressure towards the cold chamber.

Figure 1: Draft of the planned experiment. Left side, top to bottom: Gas inlet with diffuser plate, first recipient with extractor gauge and turbo pump (closable with corner valve), gate valve to be closed for phase 2, defined conductance (copper bezel), second recipient with transition to the cold chamber, which is shown to the right. It consists of: A Cold-Warm-Transition (cwt) with a baffle, the inner chamber which is plated with copper for an equal temperature distribution, a copper radiation shield.

Current status and first measurements

The warm part is already in operation. The cold chamber is currently designed and built externally. To calculate the integral outgassing in the warm part during pump down and after bake out, the corner valves are closed one at a time so the pumping speed for the valved off chamber is set to zero. The integral outgassing rate in this individual chamber is then equal to the gas flow through the bezel which can be calculated from the two measured pressure values.

Its value could be reduced by two orders of magnitude by baking the system at 200°C for 18 days. Thereby the most prominent residual gas species in the spectrum changed from water to hydrogen. The remaining water now originates mainly from the corner valves, which have been heated to only 100°C to protect the turbo pumps from excessive heat. Baking is continued to achieve lowest possible outgassing and thereby background for the experiments.

References


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FPGA Based Tunable Digital Filtering for Closed Loop RF Control in Synchrotrons

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Introduction

The longitudinal feedback system for the FAIR accelerator SIS100 will rely on digital filters for damping longitudinal bunch oscillations. Filters with a minimum time delay are needed, thus an implementation on a field programmable gate array (FPGA) is necessary. In addition, the filter implementation has to be flexible enough for a real-time adaptation of the filter coefficients during the acceleration ramp. This will enable the tuning of the longitudinal feedback with respect to the synchrotron frequency and other relevant parameters. The filter length will be considerably longer than the currently used three-tap filter of the beam phase feedback [1], offering more degrees of freedom.

Filter

In order to achieve a constant group delay an finite impulse response (FIR) filter was chosen. The fundamental operation of an $N$-tap FIR filter is the inner product of a vector containing $N$ time shifted scalars of the filter input $x$ with a vector $c$ consisting of the filter coefficients. In a tunable filter design $c$ has to be adapted to the current RF frequency. The adaption of the filter coefficients can be achieved by using a look-up table (LUT) based multiplication scheme on the FPGA. Here, a general purpose multiplier is replaced by a constant coefficient multiplier consisting of LUTs containing partial products followed by bit shifts and adders to calculate the final result. This concept, introduced in [2] was customized with reconfigurable LUTs (content can be changed during run-time) on recent FPGAs [3]. A reconfiguration can be performed in 16 clock cycles which corresponds to 160 ns in the current implementation. This is fast enough to tune the filter characteristics between the calculation of two filter outputs and thus leading to glitch-free switching.

The block diagram of the resulting dynamically reconfigurable FIR filtering is shown in Figure 1. Our implementation realizes a filter with up to $N = 64$ non-zero-taps. Between these taps a tunable number $L$ of virtual zero-taps are inserted to tune the bandpass characteristics of the filter. In addition to this tuning possibility, a larger range of input samples is considered which allows filtering of lower frequency components as well.

Simulation and Outlook

As an example, the closed-loop performance of an FIR filter used in a longitudinal beam phase feedback loop for SIS18 is shown in Fig. 2. In this nonlinear tracking simulation, $\text{Ar}^{18+}$ with a kinetic energy of 11.4 MeV/u is assumed as ion species. At $t = 2.32 \text{ms}$, dipole oscillations are intentionally induced by an RF phase shift. The amplitude of the gap voltage is 1 kV, resulting in a synchrotron frequency of 740 Hz. In this case, the filter was designed as a highpass filter with $N = 15$ and $L = 30$.

In future several new filter designs will be possible due to the large number of taps. Further studies will also deal with the optimization of the filter design.

References

Development of a tool for CBM STS module assembly

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The assembly of a silicone strip sensor with microcable and the readout chip is called in the CBM STS collaboration a “module”. To connect the double-sided CBM sensor with 1024 channels on each side via microcables to the CBM STS-XYTER chip the tab-bonding process was chosen. One microcable has 64 channels with a pitch of $116 \mu m$ and a lead width of $46 \mu m$. The thickness of the aluminium lead is $14 \mu m$ and the thickness of the polyimide substrate is $10 \mu m$. Consequently the microcable is easily floating, fragile and not easy to handle without tooling. For the assembly of the chip or of the sensor to the microcable, the microcable has to be moved in two translational and one rotational directions (see Fig. 1). Therefore the assembly tool needs at least two translational and one rotational degree of freedom to assure a correct alignment of the microcable to the sensor or chip. To realize these three degrees of freedom the microcable can be fixed and the sensor, respectively the chip, can be movable. Alternatively the microcable is movable and the sensor, respectively the chip, is fixed. Finally the microcable as well as the sensor respectively the chip are movable. For the first test version the decision was taken to move only the microcable and keep the sensor, respectively the chip, on a fixed position.

To fixate the sensor respectively the chip and the microcable on the assembly tool it is a good choice to use vacuum, because the microcable would be deformed by mechanical clamping, and the clamping tools for sensor respectively chip will reduce the accessibility of the bond pads.

To speed-up the development the 3D CAD data (see Fig. 2) were printed using a 3D plotter and tested by the bond experts before the final tool was machined out of aluminium. Due to the printing process some fine structures on the tool were not perfectly shown (see Fig. 3), but it was precise enough to decide about the handling properties of the tool. In Fig. 4 the final tool in aluminium is shown.

While using the final version of the tool it turned out that it works well and fulfills all requirements.
The sensor modules for the CBM STS comprise an STS microstrip sensor, 16 CBM STSxyter readout chips and 32 microcables of 64 leads each. The double-sided STS sensor has 1024 strips on each side. Consequently 2048 channels per module must be connected by means of 4096 bonds. It is obvious that the quality assurance of these tab-bonds is a major ingredient to the yield of module production and reliability of the detector as a whole. Especially the huge number (around 1000) of needed modules for the entire CBM STS requires to have a detailed look at the tab-bond process and its parameters, as potentially required repair actions on defective modules will be time consuming and adds the risk of additional inadvertent damage to the module. Therefore it is the best solution to improve and bring the tab-bond process to perfection before starting the serial production of modules for the CBM STS.

It is clear that for such process optimization no original full functional STS sensor and CBM STSxyter chip will be used or needed. The first reason is the costs of the original components and second reason is the missing of fast and easy ways to check the quality of the tab-bonds. For this reason, dedicated dummy-sensors as well as dummy-chips have been designed and manufactured. To check the quality of bonding two tests are necessary. One is the pull test to check mechanical adhesion of the aluminium lead of the microcable to the bond pad. The second is the electrical connectivity of the bond.

In order to make this test conclusive for the real module the microcable must the original, the surface and the material of the bond pads for dummy-sensors and -chips must be identical to the material on the original sensors and chips. Also, the silicone wafer material and thickness should be identical. If these requirements to the microcables, dummy sensors and chips are fulfilled, it is possible to transfer the process data to the serial production process.

To improve the test routines for the electrical contacts, additional pads for test needles and connections between the pads were added to the dummy-sensors and -chips. (These additional features will for sure not be part of the layout of the final devices.) In figure 1 the scheme of electrical connections is shown with the layout of the dummy chip and sensor. On the dummy chip, each second pad of each row is electrically connected to a pad far away from the tab-bond area. (The first pad of a row is like the second also electrically connected to a shifted pad.) The non duplicated pad is electrically connected to its left neighbor. On the dummy sensor two neighboring pads of a row are electrically connected together.

The idea behind this set-up is to make an electrical connection between the pad of the test needle via the tab-bond on the chip, the microcable, the tab-bond on the sensor and back to the second test pad for each row. With this simple serial routing it is possible to check 4 tab-bond connections and two leads of the microcable with one single measurement. If the connection is good the first needle is kept on its starting position whereas the second needle is shifted to the next pad of the row. This daisy chaining now allows to check 8 tab-bonds and 4 leads of the microcable in one go. While continuing this daisy chaining it is possible to check numerous tab-bonds and microcable-leads. If a broken lead or damaged tab-bond is found the first needle of the test set-up must be moved to the unconnected pad and the second needle can step further.

With this test strategy we can reduce the number of single tests, because only broken leads or tab-bonds will cause a restart of the test procedure. Additionally the test procedure could be done automatically on a wafer prober.

At the moment the dummy chips and sensors have been delivered. We are now waiting for a sufficient number of sample microcables to start process optimization.
The CBM Silicon Tracking System will be equipped with double-sided Silicon microstrip sensors, where the strips on the p-side are inclined by $7.5^\circ$ with respect to the n-side strips as well as the sensor edge. The final and homogeneous layouts for the 3 different sensor lengths, namely 22mm, 42mm and 62mm, has been elaborated. Longer sensors may be realized as a daisy-chain of two 62mm sensors. The sensors will be produced by two vendors to avoid the stop of module production in case of problems with any one single vendor.

The stereo angle of $7.5^\circ$ effects a correlation between the x and y coordinate of a bond pad on a strip. The x distance between two strips on the sensor is $58\mu m$, equivalent to the pitch of the straight n-side strips. Therefore the second row of bond pads must have a y distance of at least once the multiple of $58\mu m / \tan (7.5^\circ)$. On the sensor a pad pattern with x distance of $58\mu m$ and y distance of $\sim 440.554\mu m$ is possible, but the minimum producible pitch for the long analog microcables is in x direction $116\mu m$. In order to contact all strips, a double layered cable needs to be employed und thus a doubly staggered bond pattern is needed.

This leads to a checker-board-pattern where every second pattern-point is alternatingly reserved for a bond pad. The pitch of the bond pads is in x $116\mu m$ and in y $\sim 881.108\mu m$ (the center of the pads in the second row is shifted in x direction by $58\mu m$ relative to the center of the first row of pads). Figure 1 shows an example of the such pattern.

Figure 1: Schematic view on the bond pad and DC pad pattern.

As there are different lengths of sensors and as the pad rows should be located on the same x-position on the top edge as on the bottom edge it proved most adequate to allocate the origin of the coordinate system in the center of the sensor. Further, the distance from the coordinate center to the innermost pad row was fixed to be a multiple of the y-pitch of two staggered pad rows, namely $881.108\mu m$. Consequently the distance from the outermost pad row to the edge of the sensor is a variable of the sensor length, as the pre-chosen lengths are none multiples of this pitch.

The red and blue lines are the leads of the short $58\mu m$-pitch cable that serves to daisy chain two sensors.

Figure 2: Schematic view of a sensor to sensor daisy chain. The red and blue lines are the leads of the short $58\mu m$-pitch cable that serves to daisy chain two sensors.

These definitions together with the respective symmetry allow daisy-chaining of sensors of the same as well as different lengths to each other. Figure 2 shows two daisy-chained sensors with a microcable of a constant lead length.

Consequently, also one FEB-design may serve all sensor configurations as well as either sensor side. In figure 3 a scheme of a microcable connection between the foreseen CBM STSxyter chip and the STS sensor is shown.

Figure 3: Schematic view of a sensor to chip connection. The red and blue lines are the leads of the microcable on two different layers with a pitch of $116\mu m$.

All participating vendors will employ this layout of the bond pads even though they may vary the sensor design according to their proprietary design and production preferences.
A new Time-of-flight wall for $^{7}\text{Li}$

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**Introduction and design goals**

The beams provided by Super-FRS at FAIR will have higher energies and will be more intense than presently available. The goal of the new $^{7}\text{Li}$ setup is to fully exploit the potential of FAIR beams. With the new superconducting magnet GLAD it will be possible to deflect fully-stripped ions up to the Pb region with energies up to 1 AGeV. Also the detectors of the $^{7}\text{Li}$ setup should be able to scope with the new conditions.

One detector of the setup is the time-of-flight (ToF) wall made of plastic scintillators. The purpose of this detector is the measurement of the time-of-flight and the nuclear charge of the fragments after the reaction in the target. Together with the measured trajectory through a dipole field, the mass of the fragment can be identified. The charge is obtained by precise energy loss measurements of the fragments passing through the scintillators. With the Super-FRS at FAIR it will be possible to accelerate fully stripped beams up to the Pb region and consequently, the new ToF wall should be able to separate charge $Z$ from $Z-1$ even for heavy fragments. For Pb fragments the energy loss measurements for $Z$ and $Z-1$ are separated by 2.4 % and a charge resolution of $\sigma_{\Delta E} < 1\%$ is needed in order to resolve them. Furthermore, since the unreacted beam also hits the fragment wall, the detector must be able to maintain the performance even at high beam rates up to 1 MHz. In order to match the momentum resolution of other parts of the setup the relative time-of-flight resolution should be around 0.1‰. Since the detector is placed typically between 12 and 20 m behind the target the shortest expected flight times are about 75 ns. This results in a required time resolution of $\sigma_t < 17 \text{ ps}$ (see also contribution [1] in this annual report).

Although the current version of the ToF wall was successfully used in many experiments in the past, we plan to build a new ToF detector with superior time and energy resolution at beam rates up to 1 MHz. It is not planned to use a completely new detector concept but rather take advantage of the experience collected over the last years and advance the current design.

The detector will have four planes of scintillators and the active part will cover an area of 120x80cm$^2$. Each plane consists of 43 scintillators with the size 800x27 mm$^2$ and they are read out with photomultipliers on both far ends. The first two planes will have scintillators with a thickness of 3 mm and the last two planes a thickness of 5 mm, respectively. In this contribution we will focus on the performance of prototype detectors concerning the energy resolution and new readout-electronics at high rates.

**Prototype results and developments**

In order to test the behaviour of the detector without beam, a test stand with a fast LED was developed (see master thesis of Julian Gerbig [2]). The LED emits light in the same wavelength region as the BC408 plastic scintillator, and the intensity as well as the pulse rate can be varied. In order to obtain realistic conditions, the LED was pulsed in random mode.

![Figure 1](image.png)

Figure 1: The plot on the top shows the relative charge resolution for each frequency for two different PMs. The bottom plot shows the shift in the charge measurements for different rates.

Two different PMs from Hamamatsu were tested, both with a diameter of 1 inch. Model H6533, a very fast PM (TTS: 0.25 ns) but without active voltage divider. This

* Work supported by FAIR@GSI PSP code: 1.2.5.1.2.1.
model was used in the past experiments for the existing ToF wall (NTF). The second model R8619 is a cost effective PM with an active voltage divider (TTS: 1.2 ns).

At the beginning, the conditions of one of the last experiments were simulated. The intensity of the LED was set to simulate medium heavy nuclei, such as e.g. Ni and the voltages of the PMs were set in order to extract large charges as needed for the previously used read-out. The frequency was varied between 5 and 800 kHz. Although the energy resolution for both PMs was good for each individual rate, it was observed that the peak position shifted with frequency (see figure 1). In an experiment with varying beam rate during a spill this would lead to a bad resolution. Especially for the H6533 the shift is dramatic. For the R8619 the shift is much smaller but still visible and too large for resolving charges of heavy fragments.

The shift in the charge measurement stems from the PMs. Especially for large currents, the voltages at the last dynodes can not be kept constant and the gain of the PM is changing. The situation can be improved by taking active voltage dividers and by reducing the HV of the PMs and therefore also the anode current. But also the charge of the signal plays an important role. For small signal charges the R8619 is suited to measure the signals with a resolution (and shift) of less than 1% even for rates as high as 800 kHz as can be seen in figure 2.

It can also be seen that for too small charges, the relative resolution for charge measurements gets worse again. Therefore, for an excellent performance of the new ToF wall is mandatory to use PMs with active voltage dividers and to reduce the signal amplitudes via the HV of the PMs to a region where the PMs work best with regard to rate stability and charge resolution. This also requires a change in the read-out electronics. So far, CAEN TDC were used and the signals of the PMs were split in a time and an energy branch. The analog signal for the energy branch was delayed by about 600 ns until the trigger decision was made. Especially this long delay caused a damping of the signals by a factor 10. The new read-out will convert the analog signals immediately in logic signals with a signal width which is either proportional to the time-over-threshold (ToT) or to the integrated charge (charge to time converter QTC). This signal is then recorded by a multihit FPGA TDC such as the VFTX2 [3] developed at GSI. From the leading edge of the signal the timing can be obtained (see also contribution [4] in this annual report) and from the trailing edge the energy can be restored. In this way the signal is immediately digitized and no delays are needed. Since the VFTX2 is multi-hit capable the hits can be read out much later.

Summary and outlooks

It is planned to build a new ToF wall for the R 3B setup at FAIR. As the existing one, it will consist of plastic scintillators but we aim for an improved energy ($\sigma_{\Delta E}<1\%$) and time resolution ($\sigma_t<17\text{ ps}$) even at higher beam rates.
High precision multi-hit time-of-flight measurements at R3B

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Introduction

The kinematically complete reaction measurements at the upcoming R3B set-up require the identification and separation of heavy, relativistic reaction fragments. This requires a precise measurement of the time-of-flight in order to calculate the momentum of the particles with the necessary resolution of \( \delta p/p = 10^{-3} \). Depending on the length of the flight path and the energy of the ions, this translates into a required time resolution of about 15 ps for ions with \( A \gtrsim 150 \) [1].

To reach this goal, two new detectors based on plastic scintillators have been developed for the time-of-flight measurement: An optimized start counter and a multi-layer time-of-flight wall [2] which will provide energy loss and position information as well.

The signals of the photomultipliers will be readout by a new multichannel front-end electronic card (TAMEX). This card has been designed by the GSI CSEE group for high-resolution time and charge measurements and is a combination of the existing LAND TACQUILA FEE and a FPGA TDC from the VFTX module.

Electronics

The VFTX module [3] provides a time resolution of less than 15 ps RMS over a long time range. This is achieved by a combination of a FPGA, a TDC and an external clock signal. The TDC measures the times of the rising and the falling edges of the detector signal with respect to the external 200 MHz clock signal, see Figure 1. The FPGA stores this TDC value together with the timestamp (cycle number) of the clock signal. This way, times can be measured with respect to the arbitrary origin of the clock.

In order to measure detector times with respect to a common start or trigger signal, the common start signal has to be connected to any free VFTX input channel as well. Since the external clock signal can be applied to multiple VFTX boards, the time reference for all VFTX channels is guaranteed to remain synchronized over the whole period of the experiment.

In addition, the VFTX is able to record multiple hits per event (trigger) and channel which is not only useful for experiments with high beam intensities but also in cases where several secondary particles need to be detected, e.g. from the neutron shower in the Neuland detector [4] or if the incident particle breaks up in multiple fragments.

Measuring the times of both, rising and falling edge of the signal, provides the length of the signal which can - if properly shaped - be considered as a measure for the energy integral of the signal. For several detectors, a second electronics branch to measure the energy is therefore not necessary. For a precise charge measurement with the time-of-flight wall however, a more accurate energy measurement is necessary and will be available on the TAMEX card.

![Figure 1: Measurement of rising and falling edge of a detector signal by the VFTX card.](image)

While the TAMEX cards are not yet available, the circuit for the time measurement is already available in the VFTX modules and hence the time resolution of the whole chain detector / data acquisition / data analysis could already be tested.

Software

The current LAND/R3B analysis software land02 has been adopted to analyze VFTX data. This required the handling of multiple times per event and channel, the introduction of calibration routines and the conversion of rising and falling time signals into an energy value.

While the external 200 MHz clock signal is assumed to be sufficiently stable, the TDCs need a bin-wise calibration in order to reach the designed time resolution. The calibration is performed by recording TDC times of random input signals. The resulting histogram of raw TDC times (without considering the clock cycle) should ideally resemble a perfect rectangle with 5ns width. The calibration routine calculates the width of each time bin such, that this goal is reached, see Figure 2.

![Figure 2](image)

* Work supported by FAIR@GSI PSP code:1.2.5.1.2.1.

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Figure 2: Top: Raw times (in channels) from random input signals. The variation of the bin contents reflects the non-linearity of the TDC. Bottom: The events are equally distributed after the calibration.

Test measurements

The new start counter consists of a square plastic scintillator of 5.5x5.5 cm\(^2\) size and 0.5 mm thickness. The scintillator is read out on all four sides to improve the time resolution by averaging the four measurements. In order to reduce uncertainties from reflections of the scintillation light to an absolute minimum, the photomultipliers have been coupled to the scintillator material without any light guide.

The energy deposition of heavy ions was simulated by illuminating a small area (2mm diameter) with a Nitrogen UV laser (337 nm wave length). The time measurement was calibrated and analyzed using the updated land02 analysis software. The time resolution can be estimated by analysing the time difference of signals from opposite photomultipliers, see Figure 3. The resulting peak shows a width ($\sigma$) of 13 ps indicating a time resolution for the average of all four signals of well below 15 ps.

Summary

On the example of the optimized start detector it could be shown that time measurements with an uncertainty of less than 15 ps are feasible. The second time for the time-of-flight measurement will be measured by the multi-layer time-of-flight wall where up to 6 individual time measurements can be averaged. This will result in a similarly precise time information.

References

New time-of-flight system for the R$^3$B set-up

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Introduction

The present LAND/R$^3$B experimental set-up can be used for identifying the reaction products up to the mass region $\sim 150$. At the future R$^3$B set-up at FAIR, this problem will be overcome, and also the reaction products in the mass region 200 will be effectively separated and it will be possible to identify them. On the other hand, extending the experimental capabilities to this mass region would also imply improvements in the time-of-flight (TOF) resolution. Identification of the reaction residues in high-energy nuclear collisions is usually based on energy-loss measurements and charge-particle deflection in the magnetic field. The mass-over-charge ratio can be calculated as:

$$
\frac{A}{Z} = \frac{e}{(m_0c) \cdot (B\rho)/(B\gamma)}.
$$

Once the nuclear charge is obtained from the energy-loss measurements, relative uncertainty in the mass determination can be calculated as:

$$
\Delta \frac{A}{A} \approx \frac{\Delta(B\rho)}{(B\rho)} + \gamma^2 \cdot \Delta \text{TOF}/\text{TOF}.
$$

The challenge is to separate neighboring nuclei amounts to $\sim 5 \cdot 10^{-3}$. Thus, in order to be able to separate neighboring masses, the relative uncertainty in mass must be of the order $2 \cdot 10^{-3}$ assuming $3\sigma$ precision. The magnetic rigidity can be obtained via particle tracking with a relative uncertainty of the order of $10^{-5}$. In order to fulfill the demand on the mass resolution in the mass region 200 at 1AGeV energy, the time-of-flight (TOF) has to be measured with a relative uncertainty better than $2.5 \cdot 10^{-4}$. Considering a flight path of $\sim 20m$, this would mean that the ultimate TOF resolution should not exceed 20ps (sigma). While TOF is measured between two detectors giving start and stop signal, 20ps TOF resolution would mean that the ultimate TOF resolution should not exceed 15ps.

New TOF system

The new TOF system for the R$^3$B set-up will be based on the existing one but with improved capabilities. The start detector LOS will be made out of scintillator material, and will have dimensions of $55 \times 55 \times 0.5 \text{ mm}^3$. The produced light will be collected directly, without any light guides, by 4 photomultipliers (PM). The PMs will be read out by a new multi-channel front-end card TAMEX developed by GSI CSEE group enabling high-resolution time measurements. The stop detector will be a multi-layer time-of-flight wall with high time and charge resolution and high-rate capabilities [1].

In the following, we will discuss different effects influencing $\Delta t$ and search for the compromise between best performance and costs. We will use the statistical method [2] for calculating $\Delta t$ of a scintillator detector.

Calculations of the time resolution

There are different statistical processes which are limiting the attainable $\Delta t$ of scintillation detectors: Time spread in the energy transfer to the optical levels of the scintillation crystal, decay time of the excited states, fluctuations in the propagation time of photons through the scintillation crystal, creation of photo-electrons within a photo-multiplier, as well as the associated electronics. The first application of the statistical model for calculating achievable $\Delta t$ has been done by Post and Schiff [2]. At this place, we will not discuss the method in details but refer the reader to the paper of Post and Schiff. The advantage of this model is that all above-mentioned contributions can be studied and optimized separately, which is not always easy when using Monte-carlo simulations.

One of the important ingredients of the statistical model is the shape of the measured light pulse. This shape is of course influenced by different processes mentioned above. The primary shape is given by the light-production mechanism, and in case of plastic scintillator it has been shown [3] that the best-suited shape is given by a convolution of an exponential and a Gaussian function, so-called ExpGaussian [4]. In case of small-size scintillator detectors the light-production mechanism has a dominant role. For timing properties of larger-size detectors light transport becomes very important, and to consider this effect we have followed the work of ref. [5]. Knowing the light-pulse shape seen by a PM, using the statistical model we can calculate the contribution of the scintillator $\sigma_{sc}$.

The contribution from the PM is determined by its transient-time-spread (tts) and can be calculated as:

$$
\sigma_{PM} = \frac{\text{tts}}{2.35 \cdot \sqrt{R_{\text{tot}}}}, \quad \text{where } R_{\text{tot}} \text{ is total number of photo-electron pulses.}
$$

The contribution of electronics $\sigma_{el}$ has been measured to amount to 8ps per readout channel. Then, the total $\Delta t$ for each detector $\Delta t_{\text{det}}$ can be calculated as:

$$
\Delta t_{\text{det}} = \sqrt{\sigma_{sc}^2 + \sigma_{PM}^2 + \sigma_{el}^2}.
$$

LOS detector

For the LOS detector we have performed two sets of calculations assuming 1 AGeV $^{208}\text{Pb}$ ions passing through the detector:

1. Expensive solution: Consisting of the scintillator material:

   doi:10.15120/GR-2014-1-FG-S-FRS-06
rial EJ232Q (rise time: 0.043ns, decay time: 0.608ns, light output: 19% of Anthracene) and a photomultiplier H6653 (ts: 0.16ns), see fig. 1.

2. Cost-effective solution: Consisting of the scintillator material EJ230 (rise time: 0.5ns, decay time: 1.5ns, light output: 64% of Anthracene) and a photomultiplier R9779 (ts: 0.25 ns), see fig. 2.

Fig. 1 shows that in case of the cost-expensive solution we can reach $\Delta t$ of $\sim 4$ps. In this case, $\Delta t$ is determined only by the contribution from electronics. With the cost-effective solution, fig. 2, $\Delta t$ is $\sim$8ps, but in this case $\Delta t$ is given by the scintillator material. In both cases, the contribution of the photomultiplier, due to a large number of produced photoelectrons, is negligible. First tests with a Nitrogen UV laser have been performed, see [6].

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**New TOF wall detector**

In the case of the new TOF wall we have assumed that the detector consists of 4 layers of EJ200 scintillator material (rise time: 0.9ns, decay time: 2.1ns, light output: 64% of Anthracene) and that the signals are read by R8619-20 photomultipliers (sts: 1.2ns). We have also assumed that 1 AGeV $^{208}$Pb ions are passing through the detector. The results are shown in fig. 3. Also in case of the new TOF wall the contribution of the PMs to the total $\Delta t$ is negligible. Total $\Delta t$ well below 15ps can be reached, and is mostly determined by the scintillator material. The use of more expensive PMs or scintillator materials is thus not needed.

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**Summary and outlook**

Needed $\Delta t$ of TOF start and stop detectors of 15ps can be reach. In case of the new TOF wall $\Delta t$ is $\sim$8ps due to several-layers design. In case of the LOS detector, with a cost-effective solution $\Delta t$ is $\sim$8ps, and thus well below 15ps. With the expensive solution, we could even reach $\Delta t$ of 4ps. In 2014 prototypes of both detectors will be tested and results will be compared with present calculations.

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**References**

Development of Heteroepitaxial DoI Plates for Diamond Detectors

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Typical size of the chemical vapor deposition (CVD) homoepitaxially grown diamond material (also known as the single crystal - SC) is limited to some 5 x 5 mm² due to the availability of growth substrates made from the high-pressure high-temperature (HPHT) diamond. Presently, the only material readily available for the production of diamond detectors with larger area (∼10 cm²) is polycrystalline (PC) film grown on silicon wafers with electronic characteristics far inferior in comparison to SC material.

In order to produce a large-surface high-quality material for diamond detectors different techniques for heteroepitaxial growing of diamond films are being investigated and developed at the University of Augsburg. By using yttrium-stabilized zirconium oxide (YSZ) buffer layer to produce iridium terminated substrate on silicon wafers [1] one can grow diamond films (also know as the diamond on iridium - DoI) that are far more homogeneous than PC, however, still burdened with defects. In last few years a remarkable improvement in lowering of the level of impurities and defects was achieved so that the presently produced samples - while still not comparable to SC material - are far superior to any PC material.

Most significant structural defect arising in heteroepitaxial growth are dislocations. In a recent study [2] in which the density of threading dislocations was determined by few methods over a large sample thickness, an inverse growth depth behaviour was found. While this at least in principle confirms that films with very low density of dislocations can be grown, presently procedure would not be economically effective therefore different growing techniques - e.g. epitaxial lateral overgrowth - are being developed.

In order to assess the quality i.e. electronic characteristics of new DoI samples a typical measurement of the charge collection efficiency (CCE) is performed by using the transient current technique (TCT). Alpha particles (241 Am) are used to test the sample with different polarizations and drift fields so that the properties for both types of charge carriers can be evaluated. In Fig. 1 the set of measurements with a recent DoI sample of 190 µm thickness at different drift fields is presented showing the saturation at values above 0.8 V/µm. While the overall triangular shape of wave forms indicate the presence of the charge recombination defects, additional flat-top slope is related to losses due to the charge carrier trapping within the sample. For this sample we have measured an average CCE of about 60% for holes, which is below the level of the best samples tested (>90%) [3]. On the other hand, the CCE for electrons (shown in Fig. 2) of about 40% is much better than previously measured (∼10 %). In this case the saturation is observed at the higher drift field of 1.2 V/µm.

**References**


Laser Lithography for Production of Diamond Detectors

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Laser lithography system

Diamond detectors are usually produced from the electronic (detector) grade diamond material in a form of thin plate or film. In order to produce diamond detector, the plate has to be equipped with suitable (most often metallic) electrodes. Such metallic electrodes were - and still are - produced at GSI Target Laboratory by sputtering of one or more thin metal layers on the surface of the diamond. A particular electrode structure in that case is obtained by using stencil masks that are also a limiting factor since the minimal obtainable structure is of about 100 µm. To overcome this limitation the laser lithography system (shown in Fig. 1) was acquired and put into the operation in the GSI Detector Laboratory.

Figure 1: Lithography room in the clean room area of the Detector Laboratory. Working table with the spin coater and the hotplate (left in the photo), and the laser pattern generator with control computer (right).

The lithography system consists of Ramgraber M150 spin coater, Ramgraber M-HP150 hotplate, and the laser pattern generator Heidelberg Instruments µPG 101. The first two devices are suitable for processing of wafers up to 6" with wide variety of photoresist coatings. The µPG 101 is equipped with a solid state (diode) laser of 405 nm wavelength with maximum output power 100 mW. With present configuration the maximal writing area of 90 x 90 mm² can be processed with the minimal resolution of 1 µm. During 2013 the system was successfully commissioned and the first diamond detectors were produced and tested.

Diamond detector production

In contrast to common photo-lithography where photomasks are used to expose photoresist, in laser lithography the laser pattern generator is used to directly expose photoresist. In processing of diamond detectors two approaches are possible: in the lift-off process the photoresist coating is removed from the part of surface which needs to be metalized (i.e. occupied by the final electrode) and then after sputtering of the metallic layer over the whole diamond the remaining photoresist is "lifted-off" from the surface leaving the metallic electrode only in the previously photoresist-free area. In the other approach the metalization of the whole surface is made at first followed by photoresist coating and exposure. After developing and partial removal of the photoresist, the exposed (unprotected) metallic surface is etched until metallic layer is removed. After removal of remaining photo-resist the electrode is ready for further fabrication.

While the first approach is simpler in implementation since it does not require aggressive chemical treatment (etching), the latter is preferred in production of diamond detectors because it allows better diamond surface preparation for the metalization of electrodes.

An additional obstacle in processing of the diamond detectors is their shape and size; the typical surface of a single-crystal diamond is usually less than 5x5 mm² which presents challenge for spin-coating in cases where electrodes are up to the edge. As it can be seen from Fig. 2, during the spin coating of rectangular substrates the buildup of the photoresist beads in corners cannot be avoided. While such obstacle would be difficult to treat by the conventional photo-lithography, by recurrent exposure of the photoresist in corners we can produce desired electrode shape.

Figure 2: HADES diamond detectors prepared with the Cr+Au metalization, electrodes are processed with the laser lithography. Left: the corner of the diamond plate with the photoresist bead buildup, right: the electrode after etching and the photoresist removal. The feature size (gap between the electrodes) is 80 µm.
Optimizing the manufacturing method of detector parts

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For the Forward GEM-Tracker of the PANDA experiment at FAIR [1, 2], as part of structural elements of the so-called GEM-Disc detectors, rings with high dimensional stability and optimized material budget need to be produced. The parts are up to 1.5 m in diameter, 8 mm width and only 0.5 mm thick. They need to withstand forces of up to 15 N cm⁻¹ in radial direction. Parts made from conductive material as well as highly isolating ones are required. Industrial products with the appropriate features are not available and thus the process was set up and optimized at GSI.

Finite Element Method (FEM) simulations (see figure 1) were done precedent to manufacturing sample parts. The results of these calculations show the necessity of uniform material properties in direction of the load. This can be achieved by compounds with specific material orientation. Composite materials of carbon fibre and resin have excellent properties in elastic modulus and tensile strength, and are electrically conductive. Compounds of glass fibre are non-conductive but have a lower elastic modulus. Currently fibres made from basalt are under test which offer intermediate properties. They are non-conductive, stiffer than glass fibres and commercially available at moderate prices.

To achieve a uniform fibre orientation in the rings appropriate for the orientation of the radial loads they should withstand, a winding apparatus (see figure 2) has been build where the fibres are wound up to a spool. The winding motion is achieved by rotating the spool around its axis. A motor/gear/brake combination applies a constant tractive force on the roving (a bundle of fibres) which allows a controlled stacking of the fibres without larger flaws and with the desired high amount of fibre content (>60%) in order to maximize the stability and minimize the material budget. Several types of resin have been used in the tests, the final choice will be made taking into account the need for ageing-free operation of the detectors. The winding is made up to a larger outer diameter of the ring than necessary. The excess material is later removed by milling. Also the connection to the centre bar and additional geometry (holes, chamfers, fillets etc.) are milled.

After producing parts of different material combination test for mechanical, chemical and physical properties will be performed together with the collaborating universities. Based on this tests both material and geometry will be optimized. By comparing the FEM results with the actual behaviour of the parts the simulation settings will be optimized. This will be very helpful for the simulation of other detector parts made of composite material.

References


Characterizing the SOFIA/ANDES TwinMUSIC

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Preliminary values for the resolutions of various figures of merit have been deduced by the SOFIA TwinMUSIC\textsuperscript{[1]} for the spectra of isotopes obtained from the fission of $^{238}$U. The energy-loss resolution was measured to be $\sigma_{\Delta E/E_{\text{beam}}} = 0.34\%$ with P25 gas (Fig. 1). This leads to a charge resolution of $\sigma_{Z_{1,2}} = 0.23 \pm 0.01$ for the measurements in $\frac{1}{2}$ of the TwinMUSIC and $\sigma_{Z_{1,2}} = 0.31 \pm 0.02$ for the sum of both. The steep falloff of $\Delta t_{10-90\%} \approx 150$ ps of the drift times close to the cathode measured for single anodes yields a corresponding resolution of the straight-line fit to a track through the active volume of $\sigma_{dt,\text{fit}} = (268 \pm 40)$ ps (Fig. 2). For the electrical field settings applied the measured drift velocity is well reproduced by Magboltz simulations. After fine adjustment of the drift-times with the help of an adjacent MWPC, a position resolution for the single anode of $\sigma_{x,PB} = (28 \pm 11) \mu m$ and $\sigma_{x,FF} = (47 \pm 13) \mu m$ for the primary beam and fission fragments, respectively, can be deduced (Fig. 3). Consequently, the angular distribution of the fragments of $\approx 40 \text{mrad}$ could be measured with a precision of $\sigma_{\Theta,FF} = (0.13 \pm 0.10) \text{mrad}$ by eventwise tracking.

The analysis of the data is still ongoing, further refinements on the achieved resolutions are to be expected. Isotopic mass yields have been be deduced and published elsewhere\textsuperscript{[2]}. Changes in the design of the TwinMUSIC detector system are ongoing and will allow for an even better charge, position and angular resolution. We are aiming for a full 3D tracking operation with rates of $1 - 2 \text{MHz}$ with a non-triggered DAQ. The potential of a low-pressure operation ($0.2 - 0.3 \text{atm}$) and the application of other, 'faster' gas mixtures will be tested too.

The next physics run is already scheduled 2014 at CaveC looking into more details of the isotopic mass distributions. In the far future, a more complete set of measurements will be performed in the context of R\textsuperscript{3}B (Reaction studies with Relativistic Radiative Beams) at the FAIR (Facility for Antiproton and Ion Research) project at GSI/Darmstadt. Dedicated detector developments will be performed for those endeavors which foster similar developments e.g. for the instrumentation of the SuperFRS.

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NeuLAND - from prototypes to double-planes


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Overview

During 2013 the NeuLAND (new Large-Area Neutron Detector) project passed the important step from prototype tests to series production. Being one of the key instruments of the R3B experiment [1] the NeuLAND demonstrator will be utilized in the 2014 beam times together with demonstrators of other major R3B components.

NeuLAND is a highly granular detector composed of 3000 scintillator bars with a total volume of 250x250x300 cm$^3$. It enables the detection of fast neutrons with high efficiency, high time and spatial resolution and a high resolving power for multi-neutron events [2].

Despite the compact cubical arrangement of the NeuLAND components, the detector is built up from individual subgroups with an independent functionality, the so-called NeuLAND double-planes. This modular design facilitates maintenance and it allows upon experimental needs to split the detector in subdetectors being located at different positions with respect to the target area.

NeuLAND Double-Planes

During the previous year the first three double-planes of NeuLAND have been built. Here, we report about its different building blocks, the assembly into the double-plane structure and into the demonstrator frame. A double-plane is built up from 100 scintillator bars, 50 forming a vertical / horizontal oriented plane each. 200 photomultipliers (PMTs) serve to read out the scintillator bars from both far ends and consequently 200 channels of high voltage supply (HV) and read out electronics are required for each double-plane.

Scintillator Bars

The heart pieces of NeuLAND are the fully-active scintillator bars from BC408-equivalent with dimensions 250x5x5 cm$^3$ of rectangular shape. To avoid light losses at transitions between different materials, the bars are produced in one piece with its light guides at the two far ends. The light guides of conical shape are 10 cm long and connect the quadratical surface with a one-inch circular surface, thus leading to a total bar length of 270 cm. Within a frame contract concluded in 2013 the scintillator bars can be ordered in several fractions to fixed conditions over a period of four years. Within the first order 430 bars have been purchased allowing together with the prior existing

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200 bars to build up six double-planes, thus a 20% NeuLAND demonstrator. The scintillator bars are delivered with reflective and with light-tight wrapping.

Prior to their assembly into double-planes the bars undergo a site acceptance test, controlling both the quality of the scintillator material itself and the surface finishing. The test procedure developed and carried out by the contributing NeuLAND collaborators comprises a measurement of the response to cosmic rays and a measurement of the light transport using a light emitting diode (LED) shining in at one far side of the scintillator bar and being detected at the opposite side. The resulting data are compared to the results for a quality-proven reference bar. Figure 1 shows a typical QDC spectrum from such a combined cosmic and LED test.

![Figure 1: QDC spectra (counts vs. channel number) taken for the reference bar (red) and bar 29 (blue) of 2013 delivery. The prominent peak at about channel number 900 originates from the LED pulse, while the broad peak at channel number ≈300 stems from cosmic rays traversing the bar.](image)

**Photomultiplier**

For the light read out from the scintillator bars one-inch PMTs are connected to the far ends of the scintillator bars. The selected NeuLAND PMT R8619-20 comprises high-quality performance with cost-effectiveness: a fully active voltage divider has been developed for the use in NeuLAND in order to minimize the current demands. For the PMTs, as for the scintillator bars, a frame contract allows the fractional purchase at fixed conditions within the next four years. In the first order, PMTs to assemble the 20% demonstrator have been purchased.

The light-coupling between scintillator bar and PMT front face was subject to investigations taking into account not only the maximization of light read out, but also the long term sustainability and the possibility to apply the coupling material to vertically and horizontally oriented PMTs. A coupling via silicon glue was selected after curing issues had been successfully minimized.

**High Voltage Supply**

The high voltage supply for the NeuLAND PMTs is supposed to be unitized in a manner, that each double plane is equipped with its own high voltage distribution system close by, thus enabling the modular operation of NeuLAND double planes. The final layout of the high voltage system is under investigation at the moment. During the 2014 beam times the NeuLAND demonstrator will be brought into operation using commercial high voltage supplies available from other GSI detector systems.

**Read-Out Electronics**

The current concept for the read-out electronics is based on a concept originally developed within the FOPI collaboration, the so-called Tacquila readout system. The system provides a fully integrated solution of both charge and time measurement behind a dedicated frontend-card which is used to condition and split the signals. Here, one part is directly connected to a QDC board, while the other is put through an discriminator and further provided to the time measurement using an ASIC based solution. A dedicated frontend has been developed and commissioned in the last years, using the LAND detector, providing an optimized signal treatment for photomultiplier signals. The frontend cards are controlled using the TRIPLEX card [3] which is also used to provide monitoring access to each channel in the electronics. Currently a new electronic readout system, based on the FEBEX readout architecture utilizing an FPGA TDC [4] called Tamex has been designed, and first prototypes are currently being built. The system makes use of the previously done developments, as it is compatible to the existing analog frontend, discriminator and controls environment, by reusing the already existing cards design. The digital backend does not rely any longer on the out phased ASIC and is furthermore multi-hit capable, as well it provides time-over-threshold information. All double planes as shown in figure 3 will such be equipped with their individual readout electronics for 200 channels, and can be operated in a self-sustained manner, making best use of a fully modular design.

**NeuLAND frames**

A dedicated frame structure was designed to assemble the scintillator bars and PMTs into double-planes. Fig. 2 shows from left to right an empty double-plane frame, a frame with half of the bars mounted and a fully equipped double-plane frame. Each bar is separately mounted to the frame using a block holding structure, which fits to the conical endings of the bars. In order to protect the horizontal bars from bending in the middle, each bar is supported twice using a metal band structure with individual segments for each bar (visible on the photograph in the middle of fig. 2).

The PMTs are mounted to the bars via guide tubes from stainless steel. A light-tight connection to the holding
blocks is provided using O-rings. The far end of the guide tube is closed with an endcap containing a bajonet lock allowing an easy access to the PMT for maintenance. The signal and HV-cables are fed through an elastomer cap for light-tightness.

The signal and HV cable of the PMTs are connected to collector boards mounted along the read-out sides of the frame. Connections to these boards are provided via LEMO and CLIFF contacts, again allowing for an easy exchange of PMTs in case of maintenance. From the boards the cabling to HV distribution and to the readout electronic is provided via multipin connectors.

Assembly of NeuLAND substructures

A NeuLAND rack with two-fold purpose was built, see fig. 3. It serves for assembly of the NeuLAND double-planes and it allows to host up to six double-planes, thus the NeuLAND demonstrator.

The assembly, cabling and the commissioning of the NeuLAND double-planes is carried out by the funding collaborators.

Results from the Experiment S406

In November 2012 150 scintillator bars in a special configuration with 15 layers of ten vertical bars each were exposed to monoenergetic fast neutrons stemming from deuteron breakup reactions in a CH$_2$ target, see last year’s report for details [5]. Here we report about the status of the analysis of the collected neutron data and its implications on the NeuLAND simulation algorithms.

The calibration of the NeuLAND data taken in this experiment (S406) is completed. Apart from the usual calibration steps special care has been taken of the walk correction of the NeuLAND Tacquila channels. It improved the earlier reported value of time resolution for deuteron beam from $\sigma_D^P = 115$ ps to 96 ps. The data collected allow a detailed study of hit patterns of neutron-induced particle tracks. A top view of one event with a neutron interaction in the first plane is illustrated in fig. 4. One digit in the histogram corresponds to one bar. The neutron impinges from the left side. A high-energetic secondary particle is produced, which propagates through the detector (total depth of 0.75 m), indicated by the strict time order of the detected signals (z-axis).

The analysed neutron data in the NeuLAND test array is used to optimize the simulations. At this stage of the data analysis the neutrons are accepted as valid hits if a proper time correlation to the beam velocity is found. This might include besides reactions on the hydrogen also reactions on the carbon in the CH$_2$ target and breakup in the close-by start detector. As the next step the analysis of quasi-free scattered (QFS) protons in Crystal Ball and Silicon Strip Detectors is performed. The typical signa-
Various quantities are regarded to compare experimental results to simulations, see fig. 5. In the right hand panel the measured probability distribution of the hit multiplicity per incident neutron is compared to the simulated one for neutron energies ranging from 200 to 1500 MeV \(^1\). As expected the hit multiplicity increases with increasing neutron energy.

The probability distribution of the total deposited energy is displayed in the middle panel and the energy deposited per scintillator bar in the right-hand panel. It turned out, that two effects play a mayor role for the description of the data within the simulation. The individual realistic thresholds from the experiment are crucial for the comparison of multiplicity spectra and the low energy part of the energy spectra. The proper treatment of the PMT saturation is necessary for understanding higher energy deposition in a single bar and for the total energy deposition in the NeuLAND test array. The slight discrepancies at lower deposited energies may origin from differences in the PMT saturation due to different exposure to magnetic fields for the different beam energies and from background effects in the experiment not yet taken into account.

\(^1\)The experimental data for 200 MeV are compared to simulation findings for 250 MeV, since the quasi free event generator was available for the slightly higher beam energy solely.

Gaussian smearing with \(\sigma = 150\) ps. The general start time value for the charge integration is determined and the energy loss of all particles in each bar is integrated, applying position dependent time decay of the signal. As a next step the hits (digis) in the detector units are treated. The saturation of a single PMT is taken into account as well as the resolution of the QDC (smearing the calculated charge with a Gaussian of \(\sigma = 3 - 4\%\)) and the individual PMT thresholds using the values obtained from data analysis. The PMT saturation formula used here \(QDC_{out} = QDC_{in} \times (1. + 0.012 \times QDC_{in})\) is in agreement with laboratory tests of the NeuLAND PMT with LED light.

On the single particle level, the light attenuation is taken into account according to the position of deposited energy in the detector and the time resolution is applied using a sophisticated hit producer (digitizer) algorithm is required, described below, in order to match with the real data from experiment.

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Figure 5: Probability distributions for neutrons of various energies from experimental data (symbols) and corresponding simulation (lines). Displayed in the left-hand panel is the hit multiplicity per incident neutron. The middle panel shows the total deposited energy in the NeuLAND test array per neutron and the right-hand panel the energy deposited per scintillator bar. For the latter the probability was multiplied with the average number of hits \(N_{mean}\) for each neutron energy.

Figure 4: Display of one neutron-induced charged particle track traversing the NeuLAND test array. The time in ns is indicated on the z-axis.
Overall a good agreement between data and simulation is found over this very large range of incident neutron energies with one consistent description of the physics processes in the $R^3Broot$ simulation. This improvement in the description is a very valuable basis for the ongoing further development of algorithms for the final NeuLAND detector.

**Perspectives**

In spring and summer 2014 beam times take place at Cave C at GSI in order to commission demonstrators of various $R^3B$ detectors. The first NeuLAND double-plane will be tested during the April beam time, for summer the commissioning of four to six double-planes (20% demonstrator) is scheduled. Due to the lack of beam time availability during 2015 at GSI, the further commissioning and use of several NeuLAND double-planes at RIKEN are planned.

**References**


Simulations of the GEM-TPC response

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The GEM-TPC detector response to 1 GeV/u $^{197}$Au projectile was simulated.

The GEM-TPC detector [1] is proposed to be a standard tracking detector for the Super-FRS [2]. The requirements for the GEM-TPC detectors are: a high rate capability (1 MHz), a low amount of material in active volume and a large dynamic range (proton-Uranium). The GEM-TPC consists of the drift volume ($20 \times 8 \times 7 \text{cm}^3$) filled with a gas and uniform electric field, GEM foil stack located under the drift volume and the strip readout plane. A schematic view of the GEM-TPC is shown in Fig. 1(top).

For better understanding of the GEM-TPC design and its further improvements simulations were performed. The following simulation codes were used: Garfield++ [3] to calculate drifts of the electrons through the drift volume, GEM stack and induction gap, ELMER software [4] to calculate electric field maps of the drift volume and the GEM foil using the finite element method (FEM).

In the first step the primary electrons from $^{197}$Au beam at 1 GeV/u and their drift tracks inside the drift volume were calculated. The drift volume filled with P10 gas at normal pressure and temperature and 400 V/cm electric field was assumed. The electrons position and time distributions at the top GEM foil were obtained.

In the second step a passing of the electrons through the GEM stack was simulated. The following parameters of the GEM foils were used: hole outer radius = 35 $\mu$m, hole middle radius = 15 $\mu$m, kapton thickness = 50 $\mu$m, hole pitch = 140 $\mu$m, copper thickness = 8.0 $\mu$m. The unit cell from which whole GEM foil was constructed is shown in Figure 1(bottom). The electric field between the GEM foils was set to 3 kV/cm and the voltage over the GEM foil was set to 300 V. The gain of the GEM stack and the position distribution after the stack was calculated.

In the third step the induced charge on the readout plane strips was calculated using the Shockley-Ramo theorem [3]. The weighting fields of the electrodes and electric field map were calculated using the FEM method. The electric field in the induction gap was set to 3 kV/cm. The initial position of the electrons in the induction gap were taken according to the results from previous steps of the simulation. As an example the cluster size from $^{197}$Au projectile and relative induced charges on the different strips (0.4mm wide, 0.5mm pitch, perpendicular to x axis) are shown in Figure 2. Other characteristics such as spatial and time resolution of the GEM-TPC will be studied with this method which can help in understanding the results of the test of the prototypes [1].

Figure 1: Top-left: Schematic view of the GEM-TPC drift volume showing the cathode (brown) and the field-cage strips (gray) forming an uniform electric field in y-direction. The beam is parallel to z axis. Bottom-right: the GEM cell unit used to construct the GEM foil showing hole positions, copper part(blue) and kapton part(orange).

Figure 2: The cluster size and relative induced charge on the strips from $^{197}$Au.

References

Threshold calibration of the n-XYTER readout ASIC∗

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The n-XYTER 1.0 front-end readout-chip [1] has been widely used in various projects at GSI, including the CBM experiment, the GEM-TPC and others. The calibration of its threshold scale has however never been reported.

A threshold calibration was performed on two n-XYTER chips, operated on Front-End Board rev. D. Since in most applications the n-XYTER is used without prior threshold trimming, the threshold was not trimmed before calibration in this case either (all trim registers were set to 16). The Vfb register was set to 50, VbiasS adjusted such that the baselines are at around 2000 ADC units, and all other settings were kept at the roclib (rev. 4174) default values.

To determine the absolute value of the thresholds, pulses of the n-XYTER internal test pulser were injected in groups of 32 channels simultaneously. The number of the channels which the pulses were simultaneously injected to appeared to have no effect on the thresholds. A scan over pulse amplitudes (controlled through the cal register) was performed (Fig. 1). The threshold was considered to be equal to the pulse amplitude whenever the pulse detection efficiency was 50%. The corresponding amplitude, expressed in units of cal, was determined by fitting the scan data with an error function. Then a the calibration of the cal register gain was performed individually for each channel, at low thresholds: the pulse amplitude was measured in the n-XYTER slow lane, digitized with the on-board ADC and converted to the physical units using the calibration [2].

In Fig. 2 an example of the obtained threshold distributions for all channels of one chip, at three different vth register settings are shown. The mean thresholds as a function of vth for the two different chips are shown in Fig. 3 (the error bars are the variances). It can be seen that both the channel-to-channel as well as the chip-to-chip threshold variations are large (if no threshold trimming is done). In applications, where precise threshold setting is necessary, it is therefore recommended to perform the threshold trimming first, and then to redo the threshold calibration. The developed algorithms can be reused. For rough estimates the Fig. 3 can be used.

References

Figure 1: Example for the dependence of the detection efficiency vs. cal register setting.

Figure 2: Example of the distributions of the thresholds of all channels in one chip at various vth settings.

Figure 3: Threshold calibration plot. Points are shifted by ±0.15, and ±0.45 in x to improve visibility (initially they were at multiples of 5).

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Time and trigger distribution for NUSTAR DAQ systems

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NUSTAR experiments will be based on a complex smorgasbord of devices and detectors of many different types with wildly varying speeds. Merging the data meaningfully together requires proper timing distribution and trigger interconnections. With detectors spread over different experimental areas, sometimes hundreds of meters apart, and often-changing experimental set-ups, a flexible integration approach is the key to success.

Time distribution

NUSTAR DAQ systems need distributed timing signals for two purposes:

- Time-of-flight measurements. The most demanding of these measurements (< 10 ps at short distances) are driving the precision requirements.
- Inter-system event synchronisation. The event-wise data from different detectors, operated with common triggers but in separate dead-time domains, can be merged based on time. Requirement: a few 10 ns.

The FAIR infrastructure caters for these needs by two developments for the accelerator systems: BuTIS [1] and White Rabbit [2]. The Bunch Timing System distributes a stabilised frequency using optical fibres to distribution boxes that can be located in each experimental area. These reference signals can then be further sent to front-end boards that perform high-precision time measurements. The reference signal is effectively used to drive the front-end clock. Measurements have shown an precision better than 20 ps between systems separated by 2 km of optical fibre. For absolute timing, BuTIS-derived timing requires cooperation with an external reference to label the clock cycles, e.g. White Rabbit.

White Rabbit is a synchronous Ethernet protocol, i.e. the clocks of all switches and interface cards are synchronised to one device. It has demonstrated synchronisation better than 100 ps/km [3]; fully sufficient for all but the most demanding measurements. In addition to synchronising time, White Rabbit acts as 1 Gbps Ethernet connection.

For systems with lower timing requirements (~10 ns), which do not need a network connection, or when the overhead of aligning the local clock cycles with synchronous Ethernet is too constraining, a light-weight serial time distribution protocol is available [4]. Sender and receivers do not need to operate with the same clock frequency: the protocol is also uni-directional and medium independent.

Trigger distribution

Spatially distributed NUSTAR experiments require a very flexible scheme for connecting systems, and their triggers. The trigger logic of an experiment needs to communicate with participating detector systems, to

- receive trigger signals for coincidences.
- send master start and trigger decisions to front-end and read-out systems.
- receive dead-time information for use as veto signal.

These signals must be reasonably fast, with at most a few µs latency. (With analog delay lines this would have been a few 100 ns.) Thus, transport over any packet-switched network is not feasible, and hardware signals must be used. Manual changing of the hardware connections is very time consuming, especially so in the generally non-accessible SuperFRS tunnel. A staggering number of direct peer-to-peer connections would be needed with many detectors. Instead, remotely controlled FPGA-based switch-boxes are placed to allow the maximum flexibility. This approach works directly with trigger signals and dead-times, as those carry binary information.

For an MBS-compatible TRIV A-style trigger a few bits of information must be distributed (trigger number, event count, reset signal). For the systems to work correctly in sync, it is also necessary that the master listens to the dead-time of each involved slave. In order to avoid a dedicated electrical bus, connecting all systems in a hardwired dead-time domain, a uni-directional serial trigger protocol distributing triggers from the master module can be used, as demonstrated in a prototype environment [4].

Directing data-flow from arbitrary front-ends via event builders and time sorters to online analysis and storage is straightforward using switched Ethernet connections.

References


* Work supported by FAIR@GSI PSP codes: 1.2.2.4., 1.2.5.1.4. and 2.4.3.1.
TRLO II — friendly FPGA trigger control

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An easy-to-use command-line tool has been developed to simplify configuration of the TRLO II trigger logics. The system has also been enhanced with a serial trigger distribution protocol, to allow for greater flexibility in connecting multi-branch systems. The flexible FPGA trigger control TRLO II [1] for VULOM and TRIDI modules [2] has been used in over a dozen experiments with a number of different experimental setups. The system incorporates the functionality of most logic NIM modules. It also has features for advanced monitoring, e.g. recording of trigger alignment as well as plenty of general and specialised scalers and timer latches.

trloctrl — friendly setup utility

With around 60 types of 500+ setup registers, and 200 source and sink signals of comparably many variations, using the TRLO II could easily become a non-trivial task. The firmware now comes with a companion command-line interface for control, monitoring and read-out. This removes the need to set registers by compiled code. Complex configurations can be loaded from setup files, while one-off commands for testing can be issued quickly from a shell:

```
trloctrl "period(1)=2us" "ECL_IN(3)=PULSER(1)"
trloctrl --print-config
```

Most functionality is provided via a library so that it can be used by other programs, e.g. in DAQ readout functions.

Serial time distribution revisited

A unidirectional serial time distribution protocol has already provided time-stamps for event synchronisation in a TITRIS-compatible manner [3] for a few experiments. The protocol has been redesigned to allow the transmitter and receivers to run at different nominal clock frequencies. The precision is about 2 receiver clock cycles (20 ns in a VOLUM), and is thus suitable for event-synchronisation. The advantage compared to more precise solutions is the small resource usage and no need for special control of the FPGA clock. The sender and receiver require about 100 and 600 LUTs of general logic in a Virtex-4, respectively.

TRIMI — trigger distribution

To enable modules running the TRLO II to act as TRIVA replacements when operated with the MBS, a register-compatible mimic has been developed. This (TRIMI) component includes a serial protocol for trigger distribution and synchronisation between multi-crate systems. With the TRIMI essentially having its own register space, connections are controlled by a separate program: trimictrl. The peer-to-peer-like serial protocol makes it easy to configure inter-system connections via remote control.

The master TRIMI transmits the trigger number and event count for each read-out trigger as a serial message, which is received by connected slave modules. In return, the slaves send their dead-time signals, which can be fanned-in on the way or collected individually by the master. In the latter case, the collecting module (master or intermediate, see Figure 1) also has the ability to record the duration of dead-time for individual slaves, allowing event-by-event performance investigations.

The FPGA footprint in a VULOM4 is about 1350 LUTs (7%), of which 1050 are related to the multi-system link capability. About half of those can be attributed to the full flexibility in which module in- and outputs are used.

After extensive synthetic tests, it is now being set up and verified for use in a detector test run in Cave C in 2014.

References


A 400 kA Pulsed Power Supply for Magnetic Horn at the pbar Separator

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In the planned FAIR pbar separator [1] scheme magnetic horn will be used as a focusing device for highly divergent antiproton beam as it is already in operation at CERN [2] successfully. To achieve the desired operational performance from the horn, it needs to be powered with a very high electrical current pulse of 400 kA peak amplitude with repetition rate up to 0.2 Hz. To limit the power consumption and associated thermal and mechanical stresses on the load-system the pulse duration should be as short as reasonably possible.

As shown in Fig. 1, a high-voltage, energy storage capacitor bank will be charged by a dc supply to the rated voltage. This stored energy will be released on horn through switches and the discharge path, which includes a set of coaxial cables, adaption box and a radiation-hard stripline. An Adaptive Control Unit will provide communication interface between the accelerator control system and horn system. Possible technical realization of this system has some key design aspects. Due to the building construction and radiation protection limitations, physical distance between the power supply and horn is ≈ 65 m. This means additional parasitic impedance. Therefore, resistance and inductance of the discharge path should be as small as reasonably possible. Another key element will be the necessary high voltage switches. A mini-workshop was organized on “Switches for FAIR-Magnetic Horn Pulser System”. For the given the operating parameters, among the possible switch types are ignitrons and solid-state switches. As solid-state switches are not well-known in this power regime presently, the most likely solution seems to be the use of ignitrons. As an attempt for the systematic risk management, meeting has been organized with project control to address the safety concerns due to the mercury contents of the ignitrons. As a risk mitigation strategy, it has been decided to provide a shielding mechanism around the ignitrons in the form of metal containers for effective mercury containment.

Fig.2 shows the basic circuit to produce the required current pulse. A capacitor bank of ≈ 2 mF is charged to a voltage ∼ 15 kV and then discharged through switch S_D in a directly coupled damped circuit with ≈ 1.5 µH inductance and resistivity of ≈ 5 mΩ. These values represent calculated total effective inductance and resistance, L_S and R_S respectively, of the system. The horn can be regarded as mainly an inductive load with small series resistance. The diode stack D is used to protect the capacitor from excessive reverse voltage during falling period of the horn current. Energy-damping resistor R_E is basically a protective device to dump the significant amount of magnetic energy and thus critically damp the horn current. The whole stored energy is dissipated during each operating cycle. In order to study the transient electrical behavior of the pulser circuit, an LTspice simulation [3] has been performed using calculated values of R, L, and C of major system components. A critically-damped horn current waveform, as shown in Fig.3, with 400 kA peak amplitude and duration of 125 µs FWHM has been calculated.

References

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Ion Optics of the High Energy Storage Ring for Operation With Heavy Ions

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Introduction

In this report we show the latest improvements of the optical properties of the High Energy Storage Ring (HESR) for the operation with heavy ions.

Modified ion optics of the HESR

The ion optical lattice with $\gamma_{tr} = 6.2$ [1], which is the standard optics for the PANDA experiment, was taken as a starting point. This lattice has low-beta insertions in the PANDA straight section. Apart from their main function (strongly focus the beam in the interaction region) it drives the amplitude functions to high values around the interaction point. In the case of the SPARC experimental program such amplitudes are not needed. Thus, by varying the strengths of the quadrupoles in the zero-dispersion straight sections a more relaxed behaviour of the beta-functions could be achieved. More precisely, the maximum beta amplitudes \((\beta_x, \beta_y) = (222 \text{ m, } 172 \text{ m})\) were decreased to \((172 \text{ m, } 153 \text{ m})\), respectively (see Fig. 1, around \(s = 510 \text{ m}\)). This results in a smaller beam size and in an enhanced acceptance for operation with ions. Consequently, the calculations showed an increased dynamic aperture. A working point for the new optics is currently at \((7.63, 7.60)\).

Closed orbit bump at internal target location

In order to have the best possible beam-target overlap a feasibility of a closed orbit bump at the SPARC internal target location in the arc was investigated. With a present set of corrector magnets [2], only 3 correctors in the vicinity of the SPARC setup can be used for creating a bump. It allowed for varying the amplitude of the closed orbit at the given point. We proved that a \(\pm 5 \text{ mm}\) bump is possible (up to \(8 \text{ mm}\) if needed). In order to additionally vary the angle of the closed orbit, one extra corrector close to the SPARC target needs to be installed.

Closed orbit correction

A closed orbit correction was simulated. On the statistics of 500 seeds it was verified (see Fig. 2) that the maximum values of the closed orbit deviation are as high as \(20 \text{ mm}\) in a horizontal and \(35 \text{ mm}\) in a vertical planes. The closed orbit could be corrected down to \(2 \text{ mm}\) and \(4 \text{ mm}\) in the horizontal and the vertical planes, respectively.

Fruitful discussions with colleagues from FZ Jülich and PANDA collaboration are greatly acknowledged.

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To strengthen the Russian Contribution to the FAIR Project it was proposed to transfer a major part of the CR project responsibility from GSI to BINP (Novosibirsk). As a first step in this progress a Memorandum of Understanding (MoU) between FAIR, GSI and BINP has been signed. According to the MoU the BINP will take over the responsibility of design, construction, installation and commissioning of the CR system and major components. In order to secure a sound technical reference for this process the GSI CR project group updated the TDR of the Collector Ring. BINP will provide an accelerator that fulfills the entire set of machine parameters described in this document. GSI remains responsible for the stochastic cooling, the RF system, the data supply, the control system and the experimental devices.

In 2013 three workshops between GSI and BINP took place, where the technical aspects of the CR magnets and vacuum system were discussed. At the end of the year a BINP project group for the collector ring was established. With the reception of the - by GSI produced - project documentation this project group started to investigate the system layout and to design and specify the dipole and vacuum units.

**System design**

3D CATIA model of the CR layout and building have been continued and completed for all ring and building sections. Modifications of the long straight sections of the CR were implemented. For the civil construction planning, major assumptions have been made for the crane and maintenance of the CR components. The CR building documents and drawings have been approved in the first iteration. Major collisions have been identified and removed in an interactive process between the engineering- and ion optical designers. Detailed requests for the supply room conditions were specified according to the component properties.

**Ring layout**

The distribution of wide and narrow quadrupoles in the ring and the overall lattice cell has been further optimized. The long straight sections of the CR have been modified to have more drift space for diagnostic devices and vacuum components. In this context seven wide quadrupoles are replaced by narrow ones. The number and position of the injection kicker magnets in the CR have been optimised taking into account 3D magnet field calculations of the whole kicker tank consisting of three modules.

**Beam dynamics**

Proposed straight section modification, where the several wide quadrupoles are replaced by narrow ones, breaks the CR super-periodicity from 2 to 1. Taking into account this aspect and new data about the magnetic field quality of all CR magnets the dynamic aperture has been calculated using the PTC tracking module implemented in the MAD-X code. In particular, the off-momentum dynamic aperture has been computed to determine the available dynamic momentum aperture for the different operation conditions as shown in figure 1.

![Figure 1: Dynamic aperture in the antiproton (left) and RIB (right) mode operation of the CR with the super-periodicity of 1.](image)

The isochronous mode of the CR has been investigated further in detail. Different sort of nonlinear sources deteriorate the time resolution. It was shown that the influence of sextupole and octupole nonlinear effects can be completely compensated using sextupole and octupole corrections. The decapole effect is the most critical aspect. Without high order correction the required $\Delta T/T$ of $10^{-6}$ for mass resolution over the full CR momentum acceptance is not achievable. Simulations show that one family of a decapole corrector installed in the dispersive part of the CR is needed. To compensate the influence of the fringe field of quadrupoles on the $\Delta T$ the octupole correction is required. Using 4 octupole and 1 decapole families one can reach a resolution of $\Delta T/T = 3 \times 10^{-7}$, which corresponds to the mass resolution of $\Delta m/m = 10^{-6}$ [1].
Magnets

According to the 9th FAIR Machine Advisory Committee recommendations a fast ramping dipole magnet for the CR (1 T/s) must be designed. The time constant of the eddy current decay inside the yoke must be less than 5 ms that requires a yoke lamination thickness less than 2 mm. Requirements on integral field quality and magnet to magnet identity have been reconsidered in this context, too. The demand on the field quality of $\pm 10^{-4}$ has been fixed only for the maximum field level of 1.6 T. In the range below 1.6 T the relative magnet field deviation can be higher with a linear approximation up to $\pm 2 \times 10^{-4}$ at the field level of 0.8 T. The parameter “magnet to magnet identity” of the CR dipole magnet of $5 \times 10^{-4}$ has been specified.

A new design of the wide sextupole magnet with a vertical corrector has been developed. The yoke length of the sextupole magnet is reduced by 10 cm. The four different coils must be embedded in the sextupole aperture over the vacuum chamber as shown in figure 2 (left). The design has been performed in such way in order to have only one power converter for all these coils.

In figure 2 (right) a preliminary design of the wide quadrupole magnets is shown with four additional coils, which produce the octupole field over the elliptical aperture with the axes of 400 mm and 180 mm. The field profile calculation has been performed using 2D and 3D OPERA codes. All these four coils together induce an additional quadrupole field component, which must be accounted by the main quadrupole magnet.

Injection/Extraction

The CR requires full aperture kicker magnets with a total kick angle of 21 mrad. The kick flat-top must be at least 440 ns with a uniformity of 2%. The field uniformity of 2% is also requested inside the useful aperture. Due to the large kicker length compared to the available straight sections of the CR, it is necessary to split the kicker into nine modules. They are placed in three tanks, each containing three identical modules.

A 3D magnetic field of the kicker magnet consisting of 3 modules was calculated. In figure 4 the magnet field distribution in the middle plane of one kicker is shown. One can see that a strong field overlap between modules takes place. The particle tracking through this field shows that the effective deflection angle of one kicker tank is 7.1 mrad. The results of the 3D field analysis allowed to reduce the foreseen total amount of kicker modules from 12 to 9.

These kickers will be used both for injection and extraction of the beam in different optical modes within the rigidity range of 8 - 13 Tm. For these purposes a bipolar kicker system is required. One of the advantages of a bipolar kicker system is the possibility to determine the working mode of extraction or injection within a very short time ($\mu$s range).

Vacuum system

A bake-out of the vacuum system is not foreseen to be installed in the MSV of the FAIR project. However, the possibility of bake-ability in future has been considered. It was agreed that, if it is possible without extra cost and extra development efforts, all components should be designed in such way that they can be baked-out up to 300°C after the MSV if necessary. In this case appropriate materials for bake-out have to be chosen and installation procedure must be foreseen. For all magnets the combination of magnet yoke aperture, actual vacuum chamber layout and estimated beam shape was analysed together in order to derive the available space for thermal insulation.

For the dipole vacuum chamber the shape and wall thickness must be designed considering dipole requirements to have the possibility of fast ramping of 1 T/m.
**Stochastic cooling**

The procurement procedure for the 1-2 GHz power amplifiers at the kickers was underway in 2013. The intermediate Cu cryoshield was assembled, successfully mounted into the prototype pick-up tank and finally gold plated. The notch filters have been finalized. Progress was made towards the design of the electrodes of the Palmer pick-up. More information one can find in ref. [2]. The new software development for Palmer cooling study has been performed [3].

**References**


[2] C. Dimopoulou et al., "Developments for the CR stochastic cooling system", this annual report

Developments for the CR Stochastic Cooling System

C. Dimopoulou¹, D. Barker¹, R. Böhm¹, M. Dolinska², R. Hettrich¹, W. Maier¹, M. Kelnhofer¹, J. Krieg¹, R. Menges¹, C. Peschke¹, J. Rossbach¹, and L. Thorndahl³
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The large-acceptance Collector Ring (CR) is designed to provide fast stochastic cooling (SC) of antiproton and rare isotope beams. A detailed specification document [1] describing the complete CR SC system in the frequency bandwidth 1-2 GHz has been released. Intensive in-house engineering activities, preparation of the technical infrastructure taking into consideration electrical and mechanical safety issues as well as critical procurements of system components have taken place during 2013.

Electrodes and pick-up tanks,
Simulations of the system performance

The layout and testing challenges of the prototype pick-up tank are explained in [1]. The new water-cooled linear motor drive units have been tested at room temperature with different acceleration profiles set by a control software. The linear motor drives fulfill the following specifications: (i) their maximum range of plunging is 70 mm following the shrinking beam size during stochastic cooling and (ii) at the end of the cycle, they move back out to their maximum aperture within 200 ms, before a new beam is injected. Their synchronous operation remains to be tested after re-assembly in the tank.

The intermediate cryoshield, which will be held at 80 K inside the pick-up tank, was successfully inserted into the prototype tank at room temperature. It consists of 4 half-shells, each 1 m long, and bears holes for the motor drives and for assembling, it is made of oxygen-free copper (Fig. 1, up). Afterwards, its pieces were polished and galvanically gold plated (Fig. 1, down), so as to reach very low thermal emissivity. The preparation of the cryoshield was a complex interdisciplinary task completed at GSI.

Simulations with the HFSS code have converged to possible designs of the Faltin-type electrodes of the Palmer pick-up [2]. The Palmer cooling performance in the CR has been calculated using a Fokker-Planck approach, modified for this purpose, and implementing the properties of the suggested electrodes. With the confidence thus gained, engineering work on electrode prototypes could start.

In parallel, a numerical model for simulating the Palmer stochastic cooling of ions in the time domain has been written, cross-checked against analytical formulae, and subsequently applied to the CR case as well as to experimental data from ESR operation.

RF signal processing and operation codes

The RF block diagram of the complete SC system and its integration into the building has been refined [3] so as to save electrical length, since the flight time of the quasi-relativistic particles from pickup to kicker is very short.

After releasing the technical specification of the very demanding 1-2 GHz power amplifiers, the procurement procedure was launched. It has led to a first round of intensive technical negotiations with potential providers, aiming at awarding the contract beginning of 2014.

The design of the notch filters was optimized and their measured RF properties lie within the specifications. The mechanical assembly, including the thermally stabilized delay line, has been finalized.

Conformal to the defined standards of the FAIR control system, a new operation program covering all cooling branches of the ESR SC system has been developed and implemented to the existing RF hardware. This is a major step towards the preparation of such operation codes for the CR system.

References


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Software development for stochastic cooling study in the time domain

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The beam dynamics under the influence of the stochastic cooling forces can be studied by a particle by particle and turn by turn simulation in the time-domain. This treatment does not involve complicated, changing frequency spectra, which anyhow are likely to be incomplete by considering the Fokker-Planck Equation and its solution [1, 2]. To keep the computation times within reasonable limits, the scaling law that cooling times are proportional to the number of particles (for zero preamplifier noise and all other parameters remaining unchanged, except the gain) has been applied throughout. A special computer code has been developed to calculate beam cooling in the CR. Preliminary results for the Palmer method are presented. A typical simulation super-particle number is about $(1 - 10) \times 10^4$.

**Time domain approach**

The time domain algorithm is developed and applied to the Palmer cooling method. The possibility of using this method for simultaneous longitudinal and transverse cooling by a suitable choice of the pickup to kicker distance was described by Hereward [3]. According to this algorithm the coasting beam is generated in a 6D normalized phase space $(X,X',Y,Y',\Delta p/p, \Delta T)$. In the time coordinate ($\Delta T$) this beam is split a certain number of samples. The time length $t_s$ of samples depends on the choice of system bandwidth $W$: $t_s=0.5/W$. Having the particle time distribution of each sample the particle mixing is simulated by a simple particle migration from sample to sample, which means the flight time variation of each particle in the sample turn by turn is calculated at $t_i = t + \Delta t_i$, where

$$\Delta t_i = T_{\text{loc}}\eta_{\text{loc}}\frac{\Delta p}{p_i}$$

Depending on the way $T_{\text{loc}}$ and $\eta_{\text{loc}}$ equal $T_{PK}$ or $T_{KP}$ and $\eta_{PK}$ or $\eta_{KP}$ respectively. At Pick-Up (PU) each sample produces a signal $\langle X_n \rangle$, which is proportional to momentum error and transverse error displacement of this sample. At the kicker (KK) the accessory of a particle to the certain sample $s$ is defined and depending on the sample number $s$ the single particle correction is calculated by

$$\frac{\Delta p}{p_i} = \frac{\Delta p}{p_i} - \frac{g}{D_{\text{PU}}} \cdot \langle X_n \rangle_s \cdot \alpha_p \cdot s(\Delta t)$$

$$X'_n = X'_n + g \cdot \langle X_n \rangle_s \cdot \alpha_t \cdot s(\Delta t)$$

where the $g$ is a normalized gain, $\alpha_{p,t}$ is damping factor, which reduces the gain efficiency due to the noise. $s(\Delta t)$ is a time profile of the signal. The Eqs. (2, 3) describe the cooling effect in the time domain approximation. One can see that for the Palmer method the momentum error of particles is corrected proportionally to the center gravity of sample, which characterized by average value of coordinate $\langle X_n \rangle$. In the transverse plane the particle coordinates are rearranged and calculated by

$$\begin{pmatrix} X_{n,P,K} \\ X'_{n,P,K} \end{pmatrix} = \begin{pmatrix} C_{KP,PK} & S_{KP,PK} \\ -S_{KP,PK} & C_{KP,PK} \end{pmatrix} \begin{pmatrix} X_{n,P,K} \\ X'_{n,P,K} \end{pmatrix}$$

$C_{KP,PK} = \cos(\Delta \mu_{KP,PK}), S_{KP,PK} = \sin(\Delta \mu_{KP,PK})$, $\Delta \mu$ is a phase advance from kicker to pick-up (KP) or from pick-up to kicker (PK). The gain damping factor $\alpha_{p,x}$ can be calculated by

$$\alpha_{p,x} = 1 - \frac{g}{2}(1 + U_{p,x})$$

Here, $U_{p,x}$ are the total noise-to-signal ratio. For Palmer cooling this value is taken from [3]

$$U_p = \frac{\delta T_{\text{rms}}^2}{A_{\text{rms}}^2} + U_{N,S}; U_x = \frac{D_{\text{rms}}^2}{A_{\text{rms}}^2} + \frac{\epsilon_n^2}{A_{\text{rms}}^2}$$

Here, $U_{N,S}$ is the ratio of the thermal noise to the Schottky signal.

**Numerical simulations**

The calculated momentum spread and emittance evolution for different gain factors $g$ are shown in Fig. 1. The Palmer cooling will be useful in the first stage of stochastic cooling of rare isotopes in the CR. After the rms $\Delta p$ decreases below 0.1 %, it is possible to switch off the signals from the Palmer Pick up and turn to Notch filter cooling. From Fig.1 one can deduce that the rms $\Delta p$ of 0.1 % becomes in 0.5 second for the U$^{92+}$ beam if $g=0.4$.

**References**

Progress in development of resonant Schottky pickups with transverse sensitivity for the CR

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With its high-intensity and high-energy secondary beams, the FAIR facility will open a window to unexplored areas in atomic, nuclear, and particle physics. To take advantage of that, the ILIMA experimental program aims at high-precision mass and lifetime measurements of short-lived nuclides which will be accessible at the exit of the Super-FRS. The Collector Ring (CR) tuned into the isochronous ion-optical mode will be employed for this purpose. As a contribution to the ILIMA collaboration, our task is to develop an innovative resonant Schottky pickup with transverse sensitivity for the CR. The pickup will be used to measure the position of each stored ion, which in turn is essential for corrections of non-isochronous effects on a particle-by-particle basis.

Just like the previous Schottky pickup built for the ESR [1], we continue with a cavity-based design to achieve a high signal-to-noise ratio owing to its resonance nature. In general, three figures of merit are used to characterize such a cavity, i.e. resonant frequency, $f$, quality factor, $Q$, and shunt impedance, $R$.

Because of the boundary conditions in three dimensions, the EM waves in a cavity can only resonate at some discrete frequencies. The detection instrument will be tuned to one of these resonant frequencies in order to obtain the maximum induced signal. As a rule of thumb, it should not exceed the cut-off frequency of the ring to avoid any propagation outside the cavity. Due to the beam pipe considerations at the CR, we choose $f$ to be about 400 MHz.

The quality factor describes how well a cavity stores electromagnetic energy at the resonant frequency. The less the EM power is dissipated away by heat conversion on the cavity wall, the higher the quality factor is. It is quantified as: $Q = f/\Delta f_{3dB}$, where $\Delta f_{3dB}$ is the FWHM of the resonant peak in the frequency domain. For the sake of high sensitivity, we want the $Q$ value to be as large as possible. Thus the material of the cavity should be a good electric conductor in order to reduce the energy loss due to heat.

Last but not least, the shunt impedance indicates the coupling strength between the cavity and the beam. Due to the same reason as for the quality factor, we want a high shunt impedance for the designed cavity. Additionally, we also require it to be distinct in respect of the transverse position, since the cavity has to identify the beam offsets. As a result, a mode geometry with a varying impedance vs. transverse position (such as the dipole mode) can be used.

Bearing these three important parameters in mind, we can obtain their values numerically by computer simulations. The simulation tool we are using is a commercial software CST STUDIO SUITE®. After the 3D model of the cavity is created and the boundary conditions are set properly, the Eigenmode Solver will calculate the EM field distribution at the resonant frequency. Then with the help of Post Processing Templates, we get the quality factor and the shunt impedance. We have studied several designs and accordingly simulated their features. Based on the simulation results, we have chosen an optimal design and have manufactured a model cavity.

![Figure 1: The schematic setup of the testing system for Schottky pickups. Taken from [2].](image)

In parallel, we have also constructed an automatic computer-controlled testing system (Fig. 1) for the bench top measurements. Until now, we have performed the measurement of shunt impedances at different transverse positions in the beam pipe opening. We fixed the rod with two supports but moved the cavity instead. The cavity was placed on a motorized movement unit, which is controlled by a motor controller. It communicates with a PC over TCP/IP, via a converter to translate between Ethernet and RS-232. Also a Vector Network Analyzer (VNA) is connected to the PC by Ethernet cables. The automatic measurement is realized by a Java program, commanding the motor controller for cavity movements, the VNA for signal processing, and the PC for data acquisition. As a next step, we will perform the bead measurements to investigate the EM field distribution in the opening.

References


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The status of the CRYRING@ESR project

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The low energy storage ring LSR [1] shall provide highly charged ions and antiprotons at low energy for two collaborations at FAIR, SPARC and FLAIR. Those collaborations intend to perform precision experiments pursuing atomic and nuclear physics questions. The LSR is a Swedish kind contribution to the FAIR facility in Darmstadt.

The LSR is the swedish low energy storage ring CRYRING modernized and adapted to the additional needs for injection and ejection of antiprotons and highly charged ions at about 10 MeV/nucleon. CRYRING has been operated at the Manne Siegbahn Laboratory in Stockholm until 2010, was dismantled in 2012 and transported to GSI in the first months of 2013. At GSI it will be installed behind the ESR, as proposed and described in detail in 2012 by a swedish-german working group [2]. This proposal has been accepted end of 2012 by the relevant committees.

CRYRING can decelerate, cool and store heavy, highly charged ions and anti protons injected at about 10 MeV/nucleon down to a few 100 keV/nucleon. It provides a high performance electron cooler and a straight section for flexible experiment installations as for instance a gas jet target. It is equipped with it's own injector and ion source, to allow for standalone commissioning. The magnets are conceived for fast ramping, such that the whole deceleration (acceleration) can be as short as 150 ms.

After dismantling the ring in Stockholm under the supervision and with the help of the Transport and Installations department of GSI the components where transported to Darmstadt in spring 2013.

The concerned specialist departments of GSI for power converters, radio frequency supplies, magnets, survey and alignment, control system as well as beam diagnostics and electron cooling, scheduled the required work for getting the ring back into operation. This includes extended tests as well as modifications to meet the GSI and FAIR standards.

A detailed survey has been completed to prepare for the precise alignment of all components in the refurbished cave. The positions of the components have been marked on the floor to prepare for installation. Dipoles, quadrupoles and sextupoles, have been equipped with measurement points for the foreseen laser tracking alignment and the position of those references have been transferred to the beam axis for each devices.

Beam diagnostic devices like the in-ring transformer and the ionization profile monitors have been tested. The ionization profile monitor was installed under vacuum at the HITRAP experiment setup and tested with alpha particles from a local source.

Engineering models in 3D of the ring and the two injection lines, from the ESR and the local ion source, are basically completed. The cable planning is ongoing as well as the installation of the required infrastructure like lighting, cooling water and miscellaneous supplies.

Much time, effort and resources went into the preparation of the cave that should house CRYRING@ESR. The former experimental installation, FOPI, has been removed with the help of the FOPI collaboration and the cave has been reconstructed. Fig. 1 shows the recently completed cave. On the roof of the cave an area for power converters has been prepared and four containers for more fragile electronic equipment were installed.

For the upcoming year it is foreseen to install the still missing infrastructure, to assemble and commission all devices required to operate the ring, to install the ring and local injector hardware and to start commissioning with the local ion source.

References


Introduction

This report gives an overview of the beam instrumentation of the CRYRING@ESR experimental storage ring that is currently in the process of installation at GSI. CRYRING@ESR (see Fig. 1), together with ESR and HI-TRAP decelerator, will provide new opportunities for various research fields. An independent RFQ injector linac is available for commissioning of the new machine where FAIR standards will be applied for the first time. Three main concepts influence aspects of beam instrumentation:

- **FESA:** CERN Front-End Software Architecture, a development framework for data acquisition (DAQ) systems. Like any accelerator equipment, a DAQ system is required to provide a FESA control interface for seamless control system integration.
- **GMT:** General Machine Timing system, a new precision timing system with sub-ns precision based on the White Rabbit protocol. One programmable timing receiver board is installed in each DAQ system and controls execution of real-time actions and DAQ triggers.
- **LSA:** CERN LHC Software Architecture, the new data supply model for accelerator components. From LSA DAQ systems receive information on beam production, e.g. ion species, energy, charge state, that is needed for on-line calculations.

Linac Injector

The injector beam line will be equipped with dual detectors as used at HITRAP consisting of Faraday cup (FC) and viewing screen (SCR) on a common stepper motor drive. Two units, one before and one after the 90° spectrometer, match the ion source beam to the RFQ entrance. Two further units match the RFQ beam to the CRYRING injection. Longitudinal matching is adjusted by a new debuncher. For phase and energy measurements, three capacitive pickups have been added. The FC readout will be adopted from existing FESA systems. The SCR readout is described in [2].

CRYRING

After transport to GSI at the end of 2012, all detectors, front-end amplifiers and special low-noise electronics were carefully checked. Non-intercepting detectors are the eight beam position monitors (BPM), an integrating/parametric current transformer for bunched/coasting beam (ICT/PCT), two ionisation profile monitors (IPM) and Schottky electrodes. Most equipment can be integrated in the new DAQ systems. Only new low-noise BPM amplifiers had to be designed with switchable 40/60 dB gain and bandwidth filter. The BPM DAQ is a new design based on µTCA components, a modern telecommunication standard with high throughput and reliability. The signals are acquired by 250 MSa/s ADCs of 16 bit resolution and position evaluation takes place directly on an FPGA. A prototype system is expected to be ready by the end of this year. For intensity measurements a VME scaler system combines signals of different detectors: Schottky and BPM sum signals, IPM count rates, ICT and PCT transformer signals. For profile measurements the IPMs are equipped with position-sensitive resistive anode encoders. The pre-amplifier signals are shaped in a spectroscopy amplifier and the output signals analysed by a peak-sensing ADC in a VME DAQ which calculates the histograms. The existing 1st turn FC diagnostics will be upgraded by new FC and SCR detectors of FAIR standard. One special screen will be added at the end of the new injection section that has been upgraded for higher injection energies.

References

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STATUS OF THE SC CW-LINAC DEMONSTRATOR INSTALLATION

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ABSTRACT

The kick-off for the cw Linac Demonstrator project at GSI was aimed at a “full performance” of a 217 MHz sc CH-Cavity at the GSI-High Charge Injector (HLI). Meanwhile the design of the key components like the 217 MHz CH-Cavity, two sc solenoids, and the cryostat itself is finalized and their fabrication has started.

The test environment at GSI is about to be completed, such that the commissioning of the sc cw Linac Demonstrator is planned in 2014, when the key components are expected to be delivered.

CW LINAC DEMONSTRATOR

The concept of a suspended support frame, which carries the cavity embedded by two sc solenoids, is followed [1]. The support frame as well as the accelerator components are suspended by eight tie rods each in a cross-like configuration (nuclotron suspension) balancing the mechanical stress during the cooling-down and warm up (Fig.1). This way the components will always stay within the tolerance limits related to the beam axis (longitudinal +/-2mm, transversal +/-0.2mm). The CH cavity is cooled with LHe directly using a He jacket out of titanium. The delivery is expected in 2014 [2]. The solenoids are connected to LHe pots inside the cryostat by copper tapes allowing dry cooling. The main coil out of NbSn and two compensation coils made from NbTi provides the maximum magnetic field of 9.3 T, and shields within 10 cm to acceptable 30 mT at the position of the neighboured cavity. The delivery is expected in 2014.

SETUP AT GSI HLI

Commissioning of the Demonstrator is planned in 2014 at the GSI HLI, which operates at 108 MHz. A new beam line in straightforward direction to the HLI, which transports the beam to the new radiation protection shelter locating the Demonstrator, was designed regarding beam dynamical simulations. The new beam line with focusing and steering magnets has been installed already as well as beam diagnostic components in front of and behind the Demonstrator. The beam line is equipped with profile grids, beam transformers, and an emittance measurement station. Phase probes are used for output energy measurements applying the time of flight (TOF) method.

OUTLOOK AND FUTURE APPLICATIONS

The Demonstrator project is a proof of principle on the CH cavity. Successful full performance tests with beam of the sc CH cavity open a broad field of accelerator applications like the MYRRHA project [3] or the sc sw-LINAC at GSI [4]. Also the extension of the Demonstrator to a string of five CH cavities is proposed (advanced Demonstrator) [5].

References


Accelerator Shutdown Report

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This report describes the main service and upgrade measures of the GSI accelerator facility in 2013. The presented information is based on the work of the shutdown coordination and the corresponding MS-Project shutdown planning.

General Overview

At the beginning of 2013 the annual schedule for operation contained a long shutdown from January till August followed by a beam period of three month. At the end of 2013 there was a short second shutdown foreseen. In April due to budget constraints this beam period was shifted to 2014. Hence there was no accelerator operation in 2013 at all and the whole year was used for maintenance und upgrade work at the accelerators. For commissioning of the different components there were 6 dedicated working periods each lasting two weeks. These periods were used to switch on these components and to check their behaviour.

Work Packages

Table 1 shows the duration of the main work packages. Figure 1 displays the distribution of about 1000 shutdown schedule entries corresponding to the main topics. The extensive maintenance of the ALVAREZ II cavity, the RF-system, as well as the chemical cleaning of drift tubes were the major work packages at UNILAC. A water leak of the first drift tube of the High Current Injector IH1-cavity has been repaired. Also emittance measurements were performed at the beam line behind the MEVVA ion source. At the end of 2013, most parts of the EmTEx (emittance transfer experiment) have been assembled in the transfer channel.

![Figure 1: Work task distribution of the shutdown schedule.](image)

**Table 1: Duration of different project tasks.**

<table>
<thead>
<tr>
<th>Work package</th>
<th>Begin</th>
<th>End</th>
</tr>
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<tbody>
<tr>
<td>Alvarez service</td>
<td>Dec 2012</td>
<td>Nov 2013</td>
</tr>
<tr>
<td>EmTEx</td>
<td>Apr 2013</td>
<td>Feb 2014**</td>
</tr>
<tr>
<td>H=2 cavity</td>
<td>Dec 2012</td>
<td>Feb 2014**</td>
</tr>
<tr>
<td>radiation resistant safes</td>
<td>Feb 2013</td>
<td>Dec 2013</td>
</tr>
<tr>
<td>SIS18 switching station</td>
<td>Jan 2013</td>
<td>Aug 2013</td>
</tr>
<tr>
<td>SIS18 beam diagnostics</td>
<td>May 2013</td>
<td>Dec 2013</td>
</tr>
<tr>
<td>ESR target section</td>
<td>Sep 2013</td>
<td>Jan 2014**</td>
</tr>
<tr>
<td>HTA beam line upgrade</td>
<td>Jun 2013</td>
<td>Jan 2014**</td>
</tr>
</tbody>
</table>

At the SIS18, the construction of the H=2-Cavity, the installation of a new ionisation profile monitor (IPM) and the NEG-coating of the triplet chamber at section 11 were dominating the shutdown work. Moreover, 11 radiation resistant safes have been installed on the ceiling of the SIS18-tunnel, to protect sensitive electronic components from radiation damage. Another major work package was the installation and commissioning of a new switching station for the SIS18-main power supply. The magnets, used for the horizontal orbit correction were equipped with new bipolar power supplies. At the ESR, the injection beam line and the target section has been redesigned and rebuild. The kicker module of the stochastically cooling device has been dismantled, repaired and reinstalled. At the HEBT, many water leaks of magnet coils have been found and repaired. Additional beam diagnostic components have been installed in the beam line from ESR to Cave A. The dismantlement of the components in Cave B, to gain space for the future installations of the CRYRING, has almost been completed. In addition all beam diagnostic systems, the vacuum system and all infrastructure installations have been checked and maintained.

Summary

Technical problems (unexpected need for repair of all crane tracks in TR-, TH- and ESR- hall, a cracked weld seam on the ESR-crane) as well as organisational problems (integration of all affected departments, delayed procurement and delivery of components) were the reasons for delays and forced a permanent adjustment of the shutdown schedule. Furthermore we have been faced with a shortage of manpower in all involved departments. About 4% of the schedules tasks have to be shifted to the next shutdown. To improve the scheduling we will reorganize the structure of the project schedule to provide a better overview. The main work packages of the next break in operation have to be discussed and defined as soon as possible.
A new PCI-express (PCIe) to optical link interface card, KINPEX, has been designed and produced to replace a current PCIe card, PEXOR[1]. It provides high speed data transfer from front-end cards to standard personal computers (PC) to support experiments with high data rates at FAIR. Both cards are equipped with a high performance FPGA to control the whole system, a four-lane PCIe bus and four small form-factor pluggable (SFP) transceivers. For the KINPEX card, we have adapted Xilinx Kintex-7 FPGA from Xilinx corp. for price-performance reason, while SCM40 FPGA from Lattice Semiconductor corp. was chosen for the PEXOR card at 2008. Detailed hardware specification is available from the reference [2].

The new FPGA firmware to operate the KINPEX card has been developed. It supports data exchange with a PC via PCIe bus, which is realized with the serial interconnect building block of the FPGA configured by an intellectual property (IP) core from the manufacturer. It is configured with a per lane data rate of 2.5 GT/s to be compatible with PEXOR. The IP core supports the physical, data link, and transaction layers of PCIe protocol and gives an example to process transaction layer packets (TLPs). The example was modified to perform 32-bit memory read/write access to control registers and four 256 KByte dual-port memories (DPMs) prepared for storage of data from SFPs. For the maximum data throughput, the DMA engine developed for PEXOR is utilized for KINPEX [1]. It provides maximum payload size of 128 bytes and performs DMA data transfer via a FIFO memory as soon as stored data reaches payload size of 128 bytes.

The firmware supports communication with front-end cards via SFPs with GOSIP (gigabit optical serial interface protocol)[3]. It is a master and slave protocol with two modes of data transfer, address and block mode, and the main feature is that one SFP port of master is capable to control multiple slaves equipped with 2 SFPs. The front-end cards (slaves) can be chained in a way that one SFP of the front-end card upstream can be connected with the other SFP of the one downstream as shown in figure 2. Payload of data is kept as 1.6Gbps per SFP as PEXOR is.

The standard data acquisition (DAQ) system at GSI, Multi-Branch System (MBS) [4], has been upgraded to support the KINPEX cards and the system with the KINPEX card is working stable with expected performance.

References

Figure 1: KINPEX, a PCIe to optical link interface card.

Figure 2: Connection of the PCIe card and the front-end cards.
Features of the new MBS Production Version 6.2

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Introduction

The general purpose data acquisition system MBS has been used in the past by a vast majority of GSI experiments. It will also be applied by many experiments at FAIR (e.g. NUSTAR) for data taking and for tests of future FAIR detector systems. A new production version 6.2 has been rolled out in 2013 to accommodate the requirements of experiments. Its new features and improvements, like support of new processor boards, PCI Express, Linux, and 10Gbit Ethernet will be described. For detailed information the MBS homepage (www.gsi.de → @work → Experiment-Elektronik → Datenerfassung → MBS) and release notes 6.2 therein can be consulted.

New Features

Linux for PCs: Currently the DEBIAN Linux versions with code names Lenny, Squeeze and Wheezy are fully supported as 32 bit machines. They have been set up to boot and run diskless as all MBS nodes.

10Gbit Ethernet: Due to ever increasing data rates, 10 Gigabit Ethernet has become inevitable and is now supported on PCs for all Linux flavours mentioned above. In a typical MBS setup a data throughput of 700 MB/s could be achieved without further software optimization.

Linux for RIO4 VME processor: Up to MBS version 5.0 LynxOS was the only supported real-time operating system available. Since the existence of LynxOS for future VME processor boards seems not to be guaranteed, an effort has been undertaken to run MBS with Linux on the RIO4. A kernel module for the TRIVA VME trigger module has been developed. MBS is now fully supported. Single cycle VME A32D32 read accesses show a 10% higher speed with Linux compared to LynxOS. Network write speed is two times faster on Linux (80 MB/s). MBS template user readout functions are available.

IPV VME processor board: According to the supplier, the VME processor RIO4 will be purchasable for some years, but a follow up model seems not to be available at the time being with the performance characteristics required. In addition, the PPC processor chip utilized on the RIO4 will not be developed further. In a survey, alternative VME processor boards have been assessed.

The IPV 1102 from the company IOxOS has been identified as a candidate for the future. Its heart is a PowerPC P2020 from Freescale. Again a kernel module for the TRIVA trigger module has been developed and the IPC 1102 is now fully integrated into MBS. Simple template MBS user readout functions and VME mapping examples for more advanced VME block accesses are available.

PCI Express based MBS readout systems: Prior to MBS version 6.2, commodity PC hardware was used solely as MBS event-builders. New hardware developments made by CSEE department of GSI (www.gsi.de → @work → Experiment-Elektronik → Digitalelektronik → Module) required to extend the MBS PC capabilities as front end readout processors.

The PCI Express data concentrator board PEXOR and trigger module TRIXOR are the base of this new readout system. LynxOS drivers and Linux kernel modules for PEXOR and TRIXOR, and MBS user readout functions have been developed. They allow to control and readout frontend electronics (FEBEX, GEMEX) connected to PEXOR via optical links.

The TRIXOR has identical functionality as the VME trigger module TRIVA. It is possible to interconnect any number of TRIXOR and TRIVA modules on a common trigger system, to setup highly flexible MBS DAQ systems.

New sorting modes in MBS time sorter process m.to:
The MBS time sorter and event-builder task is used to combine data from independent DAQ systems based on time stamp information. Up to now the TITRIS time stamp system developed by CSEE was used for this purpose.

Three new Foreign DAQ systems required to implement three new time stamp sorting algorithms: To combine the PANDA GEM-TPC system with FOPI an algorithm based on COMPASS (CERN) hardware was implemented. The EURICA experiment at RIKEN required an algorithm to combine BIGRIPS and MBS systems with the LUPO time stamper from RIKEN. Finally, AGATA and RISING MBS DAQ was combined using the AGA V A/GTS hardware provided from the AGATA community.

Currently supported MBS processor platforms

<table>
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<tr>
<th>Platform</th>
<th>LynxOS 2.5:</th>
<th>LynxOS 3.1:</th>
<th>LynxOS 4.0:</th>
<th>Linux Debian 2.6:</th>
<th>Linux Debian 3.2:</th>
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<th>Linux DENX 3.3:</th>
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<tr>
<td>LynxOS 2.5:</td>
<td>CVC, E7, RIO2, PC</td>
<td>RIO3</td>
<td>RIO4, PC</td>
<td>2.6: PC</td>
<td>3.2: PC</td>
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<td>IPV</td>
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<td>LynxOS 3.1:</td>
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<td>RIO4, PC</td>
<td>RIO4, PC</td>
<td>2.6: PC</td>
<td>3.2: PC</td>
<td>2.6: RIO4</td>
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<tr>
<td>LynxOS 4.0:</td>
<td>RIO4, PC</td>
<td>RIO4, PC</td>
<td>RIO4, PC</td>
<td>2.6: PC</td>
<td>3.2: PC</td>
<td>2.6: RIO4</td>
<td>IPV</td>
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</table>
The FEBEX board was developed in CSEE Department of GSI. It features 16 differential analog inputs, 16 differential LVDS I/Os (max. 8 outputs) and a serial multi-gigabit connections to the backplane over a PCI Express [1]. The 16 differential analog signals go through 12-bit or 14-bit multi-channel pipeline ADCs with 50 MHz sampling rate.

The FEBEX boards are designed to work with globally triggered DAQ systems by accepting user defined trigger windows. The complete control and readout logic is implemented in a Lattice FPGA. Due to the FPGA’s large memory size the trigger window can be set to a maximum of 8000 ADC’s samples (20 ns per sample). The trigger window is divided to pre- (up to 2000 ADC’s samples) and post- trigger windows, both of them are programmable. The length of the FEBEX data packed depends on the number of hits found and user defined settings. After the trigger’s processing the data is moved out in block transfer mode with a rate of up to 2 Gbits per second over copper connections (back plane) and then via optical links to the PEXOR in the DAQ computer.

For each channel in the core of the FPGA two methods for “self-triggering” are implemented: 3-steps comparator and Fast Trapezoidal Filter (FTF) for a leading edge selection and double pulse detection. The parameters of the FTF (both average windows and gap between them) are programmable (8 bit with maximal length of 255 ADC’s samples). For both methods 12-bit thresholds are implemented for each channel individually. The generated “self-trigger” is sent out to the module for trigger selection and dead-time protection (EXPLODER [1]). This signal can be used as trigger system input.

The implemented FTF gives the system possibility to work in very “noisy” environment and to detect hits with very low amplitude.

A new feature of the FEBEX board is the possibility to measure the energy of the differential input pulses. The FPGA’s core includes a programmable Energy Trapezoidal Filter (ETF) for each channel (10 bit for each parameters of the ETF). The maximal length of the filter is 1023 ADC’s samples.

Each FEBEX board can send out data packets in various formats: only ADCs traces with or without ETF data; summary data packets (measured energy and hit times) and ADCs traces with or without ETF data; only summary data packet and ADCs traces with or without ETF data, in case more than one hit was found in a single channel.

The FEBEX board can be programmed to operate with negative or positive input signals. Its core includes also slow control functionality over the optical link. The implemented SPI interface to the FPGA’s flash memory gives the possibility to check and reload the FPGA programming file.

The interface, implemented in the FEBEX broad, is designed to work with Multi Branch System (MBS) data acquisition system [2]. Through the MBS system, via the optical interface, the user has full control over all components of FEBEX: configuration, testing, start/stop of data acquisition, data readout and data logging. The MBS runs under the operating system Linux and LynxOS and supports various hardware setups. Therefore, for each user defined hardware setup, the MBS data acquisition software requires user input data, describing the hardware setup and configuration parameters.

References

[1] www.gsi.de/fileadmin/EE/Module
Status of the software development for the FAIR accelerator control system

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Introduction

The FAIR accelerator control system is currently being developed and the first prototype will be tested at CRYRING. The core parts are developed in close collaboration with CERN, Geneva, and the current focus lies on their enhancement in order to fully support the demanding requirements for FAIR. Significant progress could be achieved in the basic major frameworks: LSA for settings generation, CMW/RDA for communication and FESA for front-end software. Besides these activities, work started to support the upcoming commissioning of CRYRING. This report summarizes the developments during the year 2013.

FESA Framework

Software for the Front-End equipment control computer will be developed using the FESA (Front-End Software Architecture) framework [1], which was originally established by CERN. In a collaboration between CERN and GSI a complete redesign of the framework has started a couple of years ago. The new version, FESA-3, is now completed to be used in a productive environment. The classes for the test-operation of the proton linac ion source were developed with FESA-3 at GSI.

The new FESA-3 framework provides site-specific extensions to adapt and enhance the framework to the needs of the contributing institutes. As part of the adaptation, a set of GSI specific properties was defined and a preliminary connection to the future GSI timing system was integrated.

Not part of FESA, but tightly integrated, is the CERN network communication CMW/RDA (Common Middleware / Remote Device Access) framework. The framework, originally based on CORBA, is reworked using ZeroMQ for internal communication. GSI joined the development in 2013 to collaborate in all main parts. The new version is now stable and ready to be integrated in FESA-3.

LSA Framework

As basis for the settings management framework for the FAIR accelerator control system, the CERN LSA (LHC Software Architecture) framework [2] is used. Since 2007, a collaboration with CERN has been set up and the framework is being enhanced to support FAIR operations.

This year, the splitting of the framework components into generic functionality and institute specific parts was finalized in cooperation with CERN. A major refactoring of the framework took place during the long shutdown (LS1 at CERN) to achieve a clean and state of the art framework, following modern software architecture principles. Institute specific components were refactored according to these changes.

Concepts for enhancing the LSA framework to support flexible beam operations for FAIR have been worked out and first development started. This will enable the framework to support scheduling of parallel beams and the coherent calculation of machine settings throughout the facility.

To aid the machine modeling for CRYRING [3] and for future machines, tool development started to allow more efficient modification of the accelerator models present in LSA for new accelerators.

Other Activities

In addition to framework developments, first application development has started to support the upcoming commissioning of CRYRING in 2014. A new Device Control program is being developed as part of the new FAIR accelerator control system for device diagnosis and exploitation.

A small packaged version of the FAIR control system was developed that will be used at CEA Saclay for commissioning and test operation of the FAIR proton source. It includes FESA classes for controlling the equipment as well as an application to control and monitor the proton source. This application will be the basis for a general source control program for FAIR.

The names of the existing GSI devices were enhanced to achieve a common naming schema for GSI and FAIR devices. These changes were implemented in the present control system as a precondition for integration with the future FAIR control system.

Outlook

For 2014, the main focus of the control system software development will be the commissioning and operation of the CRYRING, which will be used as test bed for the new control system for FAIR.

References


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The progress made on the new setting generation system for FAIR and GSI regarding machine modeling and application development is reported. Developments of the LSA framework [1] are presented as part of the report on the development of the FAIR control system software [2].

**Machine modeling**

A major topic regarding machine modeling was the development of a generic model for longitudinal bunch manipulations in synchrotrons such as bunch merging and batch compression. These manipulations are implemented by operating the RF system at multiple harmonics, resulting in complex patterns of variation for frequency, amplitude, and phase of the individual cavities. An algorithm was implemented which allows the definition of any combination of merging and compression steps in any machine.

As an example, the proton stacking and compression scheme in SIS100 is described: The proton beam is accumulated by filling 4 out of 10 buckets with 4 injections from SIS18. After that, a combination of merging and compression steps is applied to gather the complete beam in a single bunch at harmonic number 5. The scheme uses two groups of RF cavities. Fig. 1 shows the temporal evolution of RF voltage and harmonic number \( h \) for one cavity of each group during this process.

![Figure 1: RF voltages for the creation of a single proton bunch in SIS100 at the injection level.](image1)

Another important topic concerned the implementation of a machine model for CRYRING, which will be controlled by a prototype of the new FAIR control system. In 2013 data on the ring hardware, such as power supply properties and magnet calibration data, and the ion optical layout, was imported into the LSA database and a hierarchy of relevant parameters created. Operational cycles were defined and corresponding set values calculated for all devices, starting from physics quantities like beam energy.

Fig. 2 displays the current in the main bending magnets for the acceleration of a proton beam from 300 keV to 30 MeV. In the second half the current is set back to the injection level again.

![Figure 2: Control system application displaying the current in the main magnets for a CRYRING cycle.](image2)

**Applications**

The development of the Java version of MIRKO was continued. On the one hand, the functionality for its use as an online steering tool was implemented. On the other hand, significant effort was put into the further integration into the LSA development and build environment.

Another important activity concerned the adaptation of the application YASP from CERN for closed orbit correction in rings to the FAIR control system. This application is intended to become a standard tool in FAIR. This work will be continued in the coming year.

**References**


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SCU system goes productive

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INTRODUCTION

The SCU (Scalable Control Unit), the future standard controller and timing receiver of the FAIR control system, is composed of a base board, equipped with a COM express CPU extension and a bus system for a variety of slave boards. A powerful FPGA (Field Programmable Gate Array) on the SCU base board and the module concept makes the platform highly flexible and scalable. A broad range of digital and analog IO functions will be provided by a set of slave boards. The SCU also implements the timing receiver for the GMT (General Machine Timing) in FAIR. The SCU is now used for the first time at CRYRING.

SCALABLE CONTROL UNIT (SCU)

The SCU (Figure 1) is mechanically a stack of up to three separated boards. There is the carrier board with an Arria II FPGA, two Small Form-factor Pluggable (SFP) slots, DDR3 RAM, parallel flash and a parallel bus (SCU bus) for controlling up to 12 slave devices. In addition the carrier board is equipped with White Rabbit [1] circuitry to realize the functionality required of the timing receiver for the GMT. A COM Express\textsuperscript{TM} module with an Intel Atom CPU is mounted to the carrier board. It has Ethernet, USB and PCIe interfaces.

![Figure 1: SCU with MIL-STD-1553 Extension](image)

An optional extension board can be connected to the carrier board for dedicated hardware solutions especially for fast digital IO or for backwards compatibility that runs for example a MIL-STD-1553 based field bus interface. The SCU works as a front-end controller. On one side it is connected to the control system via Ethernet, on the other side it controls slave devices over the SCU bus.

THE SCU AS TIMING RECEIVER FOR THE GMT

As timing receiver it receives sub ns accurate timing information over a White Rabbit link, connected to an WR Switch. The White Rabbit receiver in the FPGA runs the Precision Time Protocol (PTP) in software on a LatticeMico32 (LM32) soft-core CPU. It is able, to do time stamping and generate pulses with a precision of 8 ns. With extra IO hardware, a precision in the low ps range is possible.

SCU BUS SLAVES

The SCU communicates with devices via slave cards on SCU bus. On CRYRING different devices with variety of interfaces have to be served. For this reason a modular concept for slave cards were developed (Figure 2). This concept enables the provision of a wide range of cost-effective analog and digital interfaces. The required functionality is provided by a common base module with a powerful FPGA. The different physical interfaces are connected via interface modules. All interface modules use the same base module. A unique hardware identifier allows the auto-configuration of the firmware.

![Figure 2: Modular concept for slave cards](image)

References

Paving the Way for the FAIR General Machine Timing System

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Abstract

The task of the General Machine Timing system (GMT) is the hard real-time control of the GSI and FAIR accelerator complex with sub-ns precision. This is achieved by a distributed event generation system based on the notion of time in the facility. The prime features are time-synchronization of 2000 nodes using White Rabbit Precision-Time-Protocol (WR-PTP), distribution of International Atomic Time (TAI) time stamps, generation of trigger events for synchronization of equipment and providing infrastructure for common services of the accelerator control system. During the past two years, the foundations of the GMT have been specified, designed and implemented.

Introduction

The GMT is based on a common notion of time of all connected nodes, provided by WR-PTP [1]. A dedicated network based on Ethernet and dedicated WR switches distributes the commands broadcasted by a data master to all Timing Receivers (TR). Relevant commands are decoded and enqueued for timely execution. On time, none, one or more specific actions depending on the local configuration of the TR are executed. A central clock master serves as grand-master clock to which all nodes in the WR network synchronize their clock, phase and time. As the GMT is a time based system, the precision for synchronizing actions depends only on the quality of clock and phase synchronization via WR-PTP and not on the propagation time of commands distributed by the data master.

Hardware

More than 2000 TRs will be connected to the timing network. About 1200 Scalable Control Units (SCU) with integrated TR functionality will be the prime Front-End Computers (FEC) for equipment control and have been developed by the hardware group CSCOHW of the control system department [2]. About 500-1000 dedicated TRs of different form factors are required by beam instrumentation and Data AcQuisition (DAQ). So far, TRs in the three form factors PCIe, VME and stand-alone have been developed in a cooperation between the departments of Controls and Experiment-Electronics. As all TRs are derived from the embedded TR in the SCU, they are based on Field Programmable Gate Arrays (FPGA) from the Altera Arria® families and share many identical electronic components. The fundamental design principle is to maximize re-usability and similarity only adapting the host-bus bridge and I/O for each form factor.

Gateware

Code for FPGAs is called gateware. Although GSI’s and CERN’s TRs are based on FPGAs from different manufacturers, the gateware is manufacturer independent to a large extent. The concept is to separate functionality into different Intellectual Property (IP) cores which all have an interface to the System-on-Chip (SoC) Wishbone bus. All IP cores represent Wishbone devices that are interconnected via Wishbone crossbars. The crossbars do not only provide clock domain crossings but also allow to connect form factor specific Wishbone devices to a standard architecture common to all TRs. Each form factor needs to implement its own host-bus to Wishbone bus master bridge. The connection to the WR network providing a network interface and a WR link is always encapsulated in IP cores behind a dedicated Wishbone crossbar. All Wishbone devices provide Self-Describing Bus (SDB) records, that allow querying bus-addresses, vendor and product information. Every gateware includes at least one Lattice Micro 32 CPU (LM32) softcore [3] that allows to implement application specific firmware. Gateware and firmware is developed in collaboration with CERN in the framework of the Open Hardware Repository [5].

Driver

The main idea is to extend to SoC Wishbone bus outside the FPGA using the EtherBone protocol [4]. As EtherBone can run over any serial protocol, it only requires a form factor specific driver in the kernel implementing an interface to the Wishbone bus master interface on the TR’s FPGA. This allows EtherBone to connect to the Wishbone devices of the TR over any host-bus to Wishbone bus master bridge and even network protocols such as UDP and TCP/IP.

Status

White Rabbit Network

15 production quality WR switches [6] have been obtained in 2013. All of them are in operation and work reliably with respect to their hardware. However, gateware and software are still missing some features. A clock master switch is already installed in the final position in the existing building BG at GSI. From here, already five locations

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at the existing facility are connected via optical fiber links. A part of the links will serve to connect equipment of the existing facility to the new timing system. Another part is used for testing equipment or to gain experience with long term operation of switches and equipment. Via appropriate patches, some dedicated links of up to five kilometer length have been set-up. Moreover, several kilometers of fiber have been exposed to environmental conditions on a building roof. Results of long term tests on WR clock and phase synchronization including multiple layers of switches are very promising and presented elsewhere [8].

Data Master

The data master schedules actions by broadcasting commands to the TRs via the WR network [9]. A first data master has been set-up based on a SCU and includes dedicated firmware in a LM32 softcore. The firmware generates the commands that are broadcasted to the nodes. It can be configured and controlled via a dedicated API which is used by a Front End System Architecture (FESA) class. Since May 2013 the data master is in operation successfully with very little downtime. This data master serves as a proof of principle and will be replaced by a parallel multicore version in 2014.

Timing Receivers

The focus of the past two years has been the development of the TRs in a joint effort of different groups. With respect to hardware, work has been carried out by CSCOHW (SCU) [2] and CSCOE (VME, PCIe, standalone). CSCOTG has concentrated on gateware and software. The driver concept allows to access the TR from Linux user space via the EtherBone protocol in a transparent way independent of the host bus bridge - the same front-end software for equipment control can be used on different FECs independently of the form factor of the TR. As a proof-of-principle, functionality dedicated to the timing system has been integrated with FESA. This allows a FESA class subscribing to a so-called event-source within FESA and receiving a notification upon an event.

For the GMT, a main component of the gateware is the Event-Condition-Action (ECA) unit. It is a complex filter, comparing the event of a command received from the data master against conditions pre-configured by the TR's user. In case of a match, a pre-configured action will be scheduled for timely execution in a so-called action channel. On-time, the action channel triggers a receiving component. Here, the action such as IRQ generation, digital output or equipment action such as ramping a magnet is executed. The precision for triggering is 8 ns due to the 125 MHz system clock. If supported by the receiving component, an additional fine-delay feature allows more precise timing. All supported form factors allow fine-delay of 1 ns already in the FPGA. As a perspective, further refinement by PLL-phase-shifting (125 ps) or delay chains in transceivers of differential output pins (25 ps) might be possible inside the FPGA without the need of external fine-delay electronics.

Next to timely execution of actions, the ability for precise time stamping of triggers received by a TR is another key requirement to the GMT. As all TRs share a common notion of time, a timestamp latch unit is common to the gateware of all TRs. This feature has already been integrated by the Multi Branch DAQ System [7] and successfully tested with the form factors PCIe, VME and standalone over many weeks [8].

Conclusion and Outlook

Significant progress has been made on the hardware, gateware and software of the TRs. A timing network spanning the existing facility has been set up with about 15 WR switches. A first timing system has been set up in May 2013. Key components like the ECA unit, the Wishbone SoC architecture, the driver concept and the communication library EtherBone have been developed and implemented.

The next step is to set up the GMT for the recommissioning of CRYRING at GSI. Here, about 50 TRs are required for synchronization of equipment of the control system and beam instrumentation. At the beginning the GMT will only provide basic features. CRYRING serves as a test ground for the control system as a whole. This is important for validating the concepts, gaining experience of operation under on-line conditions and assures the quality of the components developed.

References


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White Rabbit Applications for FAIR Experiments

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Introduction

A White Rabbit (WR) based timing system will be used at FAIR as a field bus for accelerator controls. In addition WR Timing Receivers (WRTR) are required by FAIR experiments for the synchronizaton of independent detector sub-systems. For this purpose hardware latching of time stamps on WRTR has been implemented. A test bed has been set up to check this functionality. Furthermore it has been investigated if a WR synchronized 200 MHz clock can be used as reference for high precision time-of-flight measurements (TOF) with electronics resolution in the order of 10 ps RMS between independently operated and possibly far distant detector systems.

White Rabbit Timing Receivers (WRTR)

The development of the WRTR is a joint effort of the CSEE and CSCO departments of GSI. CSEE designed and produced the WRTR, while the full development of the WR timing protocols on the FPGAs of the WRTR, including Linux kernel modules and libraries for user applications. Finally the adoption of the WRTR for the MBS data acquisition system and an additional VME driver development was made by CSEE.

Three types of WRTR boards have been investigated: The PCI Express based PEXARIA5, The VME board VETAR2 and the standalone module EXPLODER2. All boards can be accessed through Etherbone via USB and the WR network. In addition the PEXARIA5 can be accessed for high speed DAQ applications via PCI Express - and the VETAR2 via the VME protocol. It is important to note, that all WRTR types provide identical functionality.

All WRTR are connected to the WR network and their time base are syntonized and synchronized using the White Rabbit Precision Time Protocol (WR-PTP) implemented in the WRTR.

Global - versus Local Triggers

Basically two types of detector systems at FAIR have to be synchronized with the WRTR. The first and traditional type is readout at the occurrence of a single (global) trigger signal, producing a so called (sub)event. In the second type, often stated as triggerless, each channel is readout if a certain individually threshold is exceeded. Thus, these kind of systems produce a stream of data, whereas the entity of an event is a priori not present any more.

Synchronization of globally triggered, but independent

sub-systems can be facilitated by latching time stamps in all sub-systems at the occurrence of the global triggers. By requiring time stamp differences to be inside an adjustable interval, data from different sub-systems can be connected in the data analysis. Synchronizing triggerless and/or globally triggered sub-systems works according the the same principle, but time stamp comparisons must be made for each individual channel or possibly groups of channels.

All these requirements can be provided with the WRTR. Synchronization of triggerless systems with WRTR is prepared and needs to be tested. It is not covered in this report.

Synchronizing Globally Triggered Systems

For this purpose a specified input channel on each WRTR is connected to a FIFO in its FPGA, where time stamps are stored and can be read out. Dead time protected and accepted global trigger signals are used to latch time stamps. The time stamps itself are 64 bit counters, currently with a granularity of 8 ns, referring to the 125 MHz WR clock.

A test system consisting of 4 independent MBS sub-systems and all types of WRTR described above has been set up. Comparing time stamps differences of all 4 sub-systems, a precision of 5-8 ns (RMS) could be achieved in long term measurements over weeks.

High Precision TOF with WRTR

The WR-PTP protocol allows the adjustment of the 125 MHz WR clock of the WRTR in the sub nano second regime. Therefore it has been anticipated as reference clock for TOF measurements in the ps range. Since the VME TDC VFTX developed at CSEE requires a 200 MHz clock, a 200 MHz clock was derived from the native 125 MHz in the FPGA of all types of WRTR and fed out. Another MBS test systems with up to 4 WRTR connected in various topologies to the WR network has been set up. The 200 MHz clock was fed into individual VFTX modules. A common reference signal was fed to all VFTX and their measured time differences estimated with a rate of 25 KHz. An intrinsic precision of 15-20 ps RMS between pairs of WRTR clocks have been observed. Long term tests revealed drifts in a band of 40-50 ps RMS for the differences of the reference signals. These results do not meet the requirements yet, but amongst others, possible improvements for the clock generation hardware have been identified.

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The credit-card sized, general purpose controls platform: HadCon2

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Introduction

The HadCon2 (http://wiki.gsi.de/EE/HadCon2) is a low-cost, credit-card sized, general purpose I/O module for detector and experiment controls as well as for small data acquisition systems.

It is the successor of the discontinued first version HadCon a.k.a. HadShoPoMo. The module has an ATMEL AT90CAN128 microcontroller providing a multitude of connectivity:

- I²C (8-fold multiplexer, 4 internally used)
- 6 channel 1-wire master, slew-controlled 1-Wire Edges
- 8 channel 8bit DAC, galvanically isolated CAN-high speed transceiver
- 8 channel 10 bit SAR ADC, single ended, or up to 4 differential
- byte oriented SPI interface
- in total up to 53 programmable I/O lines

and

- a Lattice MachX02 FPGA for fast data processing tasks.

In contrast to its precursor HadCon, in favor of a more open access and long term maintenance, it doesn’t have any CPU on board, but a USB connector to directly allow communication with any type and size of computer (e.g. standard PC, Raspberry Pi, DreamPlug,...) having an USB port on one side and at the other end the microcontroller and the FPGA.

The communication is based on an ASCII based protocol API in view of easy implementation in detector control systems like e.g. EPICS[4] and LabVIEW[5] and easy control via the command line and scripts with human readable commands to communicate with all the interfaces available.

Use Cases

Originally developed for a power monitor board (HadShoPoMo) for HADES[1] the HadCon family serves/will serve many different applications and collaborations:

- HADES MDC/RPC detector controls - EPICS controlled 1-wire devices: temperature sensors, switches, ADCs.
- HADES RPC detector - EPICS controlled CAN-based gas system
- HADES RICH detector - EPICS monitored (10Hz) current via internal ADC, in progress
- PANDA APFEL ASIC[2] - EPICS controlled, bit-banged interface to the SPI-like APFEL ASIC, in progress
- FPGA projects
  - Waveform Generator - FPGA based Waveform Generator, controlled by the HadCon2’s API
  - FPGA based 1-wire ADC - 6 channel, max. 12bit ADC to be accessed by 1-Wire protocol, in progress.

References

The GSI Event Driven TDC ASIC GET4 V1.23

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Introduction

In the scientific report 2012[1] first results of the GET4 V1.10 ASIC the first fully equiped event driven TDC prototype taped out in 2012 (see figure 1) are reported. The excellent performance regarding timing precision was reported but also some minor bugs are mentioned. To fix these bugs in 2013 a second iteration was taped out and tested. First results are presented in this report.

Logic Revision

Two faults of the read out logic have been found in GET4 V1.10[2]. A sync-flag in the epoch events was not set correctly and a setup and hold timing violation leads to data errors in the 24 bit read out mode with data rates below 160 MBit/s. To clear these faults the struture of the 24 bit serialiser was modified and the vhdl source code was corrected. Tests of GET4 V1.23 have shown that the sync flag now is set correctly and the 24 bit serialiser works correctly at all data rates.

Process Variations

The main problem of GET4 V1.10 was caused by process variation during the MPW run. The internal delays were significantly larger than in simulation and in previous ASICs. Figure 2 show the measurement results of a ring oscillator with configurable length which is integrated on the GET4 ASIC in comparison to simulation results in typical corner.

The measured cycle times of GET4 V1.10 as well as of GET4 V1.23 are significantly larger than the simulated times. The increment per stage of cycle times of V1.10 is about 6 % larger than that of V1.23. This unusual large delay of V1.10 caused several problems in getting the DLL into lock state as well as in data transfer from the TDC core to the read out logic. These problems are discussed in detail in [2]

To overcome the last mentioned problem a configurable delay element was integrated in the data transfer clock to adjust the clock phase for best fit with process speed. An increase of core voltage by 10 % as it was needed for operation of GET4 V1.10 is no longer required for GET4 V1.23.

Outlook

In the meantime also the TDC performance of GET4 V1.10 could be confirmed with GET4 V1.23. For detector tests with RPC timing detectors additional GET4 V1.23 ASICs will be bonded on PCBs to test the performance of the GET4 TDC in the 2014 GSI beam time as well as in long term cosmic tests.

References


Web interface in DABC

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User interface for DABC

DABC [1] is general-purpose DAQ framework, developed in GSI since 2007 and used in different applications. Because it cooperates with many other components (like slow control systems, other DAQ systems, online analysis), DABC requires a simple and flexible user interface for monitoring and control. Decision was taken to evaluate web protocols for implementing a user interface via normal web browser. As a starting point for development, JSRootIO project was considered.

The JSRootIO project

The JSRootIO [2] project is a new development of ROOT [3] team. Objects like histograms or graphs, stored in binary ROOT files, can be read and displayed with all modern web browsers. Usage of JavaScript allows to build interactive and very informative graphical elements.

Several important improvements were done to increase flexibility and usability of the JSRootIO graphics. A context menu was implemented, where convenient commands are provided: switch for lin/log axis, changing of draw options, toggle statistic box. Drawing and update of histogram statistic box was implemented - it is especially important for the case when histogram content is regularly updated. Also a significant performance improve (by factor 10) was achieved. At its present state JSRootIO allows to insert JavaScript-base ROOT graphics in arbitrary HTML page and provides look-and-feel of the original ROOT graphics.

A main disadvantage of JSRootIO is that it works only with ROOT files. This makes it difficult to use it for online tasks, where many objects should be frequently updated.

HTTP server in DABC

Instead of creating temporary files for online monitoring, one could provide specialized HTTP server delivering objects data directly to the browser. Mongoose [4] embeddable web server was chosen as basis for implementing http server in DABC. Mongoose implements basic web protocols and via callback functions provides possibility to construct user-defined response on the HTTP requests.

Specialized hierarchy of objects was introduced in DABC, where different kinds of data can be registered. Main aim of hierarchical organization - provide structural access to user-defined data. One could compare this hierarchy with file system - different sub-folders correspond to different parts of a big system, and files represent some parameters or objects. As response on HTTP requests, DABC server returns hierarchy descriptions (in XML files) or binary data from registered elements.

JavaScript code on the browser side interprets this hierarchy description and creates tree view, seen on the left side of Figure 1. On the right side of the web page selected items are displayed. On the example figure these are histograms, displayed using JSRootIO graphics. Also ratemeters and simple text output are supported. When monitoring is enabled, object content (histograms, ratemeters) will be updated regularly. It is possible to extend code for displaying of any user-defined kind of data.

As a result, HTTP server in very generic way provides direct access to the information from arbitrary DABC-based application. Such information can be explored, displayed and monitored in any modern web browser. No any intermediate files are necessary.

FastCGI interface in DABC

FastCGI [5] is a protocol for interfacing interactive programs with standard web servers (like Apache or lighttpd or many others). Using FastCGI, one benefits from standard software and could integrate online applications into existing web infrastructure. FastCGI server was implemented for DABC and provides similar functionality as mongoose-based http server.
Monitoring of ROOT applications

The combination of DABC as web server and JavaScript code in web browser allows to implement live monitoring of arbitrary ROOT application. With a few function calls any ROOT-based application can start HTTP server and publish various objects like histograms or graphs. Figure 1 shows browser with several histograms, produced by running hsimple.C macro from ROOT tutorials.

In Go4 [6] production release 4.6.0, DABC-based HTTP server is also provided. Without modifications any existing go4-based analysis can start a web server, where all histograms, graphs, canvases and trees are available for display. One can also browse parameters and events objects members. Moreover, via a command interface one could suspend/resume analysis execution or clear histograms content by pressing button in the browser window.

Unified interface for many components

DABC provides flexible mechanisms to integrate different kinds of data into the framework - it could be raw data from front-ends, but also information from slow-control systems. For instance, plugin for MBS [7] can retrieve both raw lmd data and statistic information from arbitrary number of MBS nodes. Or FESA [8] plugin can acquire pres-elected subset of records from accelerator control system. Via unified HTTP interface all these kinds of information can be provided to the user.

With HTTP server one could also control DABC applications and all its components. The user can define commands, which are published via web interface in the browser. Typical use-cases: start/stop file writing, toggle logging mode, reset counters, and so on. Of course, all these commands can be protected from unauthorized use.

DABC allows to run many agents (slave applications), collecting information from different sources. HTTP server, running on the master node, will provides seamless access to data from all agents. This allows to build user interface for distributed (running on many nodes) and heterogeneous (acquiring different kinds of information) systems.

Conclusion

The web interface in DABC provides a unified view for data from many different frameworks like ROOT, Go4, MBS, FESA or DABC itself; support for EPICS and DIM is in development. Web interface could be used on many computing devices and typically does not require any additional software installations - just a normal web browser. The developed interface can be directly used with arbitrary Go4-based analysis; with minimal efforts it can be enabled for any ROOT-based application. Current DABC version 2.6 with the web interface was released in November 2013 and is available on the project home page [9].

References

POLAND - Low Current Profile Measurement Readout System


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Abstract

The development of a 32 channel readout system for low-current profile measurements called POLAND (Profile Acquisition Digitiser) was done in collaboration between the Beam Instrumentation (LOBI) and the Experiment Electronics (CSEE) departments. This electronic system is capable to read out beam diagnostic devices like Secondary Electron Monitor (SEM)-profile grids, Multi-Wire Proportional Chambers (MWPC), Ionisation Chambers or similar devices of the future FAIR accelerator system. Transverse beam profiles with a time resolution down to the microsecond range can be measured with POLAND.

After intensive tests with a prototype version in recent years[1], the complete readout system, close to the final version, has been built in 2013. It contains the current-to-frequency converter units based on the QFW ASIC[2], the logic unit based on an FPGA and an optical readout for data transfer to a host PC, mounted all together in a 1U 19” rack crate. The system is designed to be read out via FESA or MBS, two standard data acquisition systems for FAIR. Together with different diagnostic systems, POLAND was tested in 2013 at different beam-tests at COSY and HIT.

The POLAND readout system

The developed hard- and software is described in [1] and in detail in [3]. The main changes from the previous version are: a compact but maintenance-friendly design, higher time resolution during the beam pulse measurement, and a daisy chain readout for easy expansion of the number of readout channels. A photography of a POLAND readout unit is shown in Fig. 1.

The system has been intensively tested in laboratories of CSEE and LOBI. During this time the FPGA software has been improved and further developed.

A first test under beam conditions was done in summer 2013 at COSY in Jülich. Here the new electronics was used for monitoring the 2 GeV proton beam. A significant improvement in beam analysis compared to existing systems was achieved. Also the time-resolved beam profile was measured to analyse the extraction structure of the COSY beam. A typical 3D measurement of a time-resolved beam profile is shown in Fig. 2.

Within a second beam test at HIT medical accelerator facility in Heidelberg both the software improvements of the readout system and the new detector components connected to POLAND could be tested.

Figure 1: Picture of a 32 channel readout system, including the four QFW units (left side) and the FPGA logic unit (middle). The complete system fits into a 1U 19” rack crate. All connectors are on the back side.

Figure 2: Time-resolved vertical beam profile measured at the 2013 COSY proton beam test. The beam extraction time was 7s with an “extra” short pulse at the end of the extraction.

Outlook

From February 2014, the system will be tested with various beam conditions at GSI experimental location UNILAC UX2 and HTP (after SIS 18) with different tasks. An important milestone will be the proton source acceptance test in summer at CEA/Saclay, France.

References

Status of the Coating Activities at the Magnetron Sputtering Facility

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Vacuum upgrade of the Heavy Ion Synchrotron SIS18

The production of thin film coatings by means of magnetron sputtering facilities has been started at GSI in 2005, in the context of the technical developments for the construction of the Facility for Antiproton and Ion Research (FAIR). In fact, to improve the beam lifetime and the beam intensity of the existing heavy ion synchrotron (SIS 18) an intensive programme for the vacuum upgrade was undertaken and among the different measures the installation of non-evaporable getter (NEG) coated pipes was considered. The production of the thin film getter was carried out in two cylindrical magnetron sputtering facilities described in details in Ref.[1], and the thin film characterization was performed by means of different techniques carried out at GSI, in CERN, and at the Magdeburg University [2, 1]. During the upgrade shutdowns from 2006 to 2009 24 dipole magnet chambers, 11 long collimator chambers and 5 straight vacuum chambers were replaced by NEG coated UHV chambers, which corresponds to app. 65% of the SIS18 circumference. The commissioning of the upgraded UHV system has been performed at the beginning of 2010 [3]: the acceleration and extraction of $2 \times 10^{10} U^{28+}$ ions, which represents an intensity increase by a factor 100, was realized. In addition the achievable $U^{28+}$ beam lifetime ($t$) was strongly improved, from $t < 1$ s before the UHV upgrade, reaching about $t = 11$ s after. During the measurements no increase of pressure was observed [3].

Collaboration with International Institutes

The experience acquired in the last years in the field of thin film coatings allowed the vacuum laboratory to carry out coating also for other Institutes. Starting from 2011 in collaboration with the company FRIATEC AG, for example, 6 ceramic chambers, elliptically shaped, were sputtered with a thin titanium layer to produce a required resistivity for NSLS-II (BNL). The collaboration, which resulted to be successfully, will proceed until the end of the current year. Additionally, collaboration with the University of Heidelberg, the University of Princeton, and Hamburg were established in the last year, beside the support on the thin film production provided to the GSI groups.

Thin film coatings for FAIR

In the frame of the FAIR accelerator complex, the use of non-evaporable getter film is still under study. One of the possible application is on the dipole magnet chambers of the High Energy Storage Ring (HESR). The HESR, which will be completely realized by the Forschungszentrum Jülich (FZJ) is dedicated to strong interaction studies with antiprotons in the momentum range between 1, 5 and 15 GeV/c [4].

The HESR dipole chambers, made by stainless steel, are more than 4 meters long, have a circular cross section of 89mm, and are characterised by a 8, 2° bending angle. For an easier integration of the dipole chambers into the sputtering system, a horizontal configuration of the facility is foreseen, and a design modification of the existing magnetron sputtering system is already ongoing, as shown in Figure 1.

Collaboration with International Institutes

The experience acquired in the last years in the field of thin film coatings allowed the vacuum laboratory to carry out coating also for other Institutes. Starting from 2011 in collaboration with the company FRIATEC AG, for example, 6 ceramic chambers, elliptically shaped, were sputtered with a thin titanium layer to produce a required resistivity for NSLS-II (BNL). The collaboration, which resulted to be successfully, will proceed until the end of the current year. Additionally, collaboration with the University of Heidelberg, the University of Princeton, and Hamburg were established in the last year, beside the support on the thin film production provided to the GSI groups.

Figure 1: Drawing of the magnetron sputtering system, which will be used for the NEG coating of the HESR dipole chambers.

References


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Status of the SuperFRS Cryogenics

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The Cooling of the SuperFRS

In March and April, 2013, two technical review meetings with R. Pengo, cryogenic expert from INFN, Italy and P. Lebrun, cryogenic expert from CERN have been organized by the cryogenic group CSCY at GSI on the issues mainly concerning the local cryogenics for Super-FRS. The challenge of cooldown the huge mass up to 1400 tons cold iron (cooldown enthalpy: about 112 GJ from 300 K to 4.5 K) has been addressed as one of the most important features of the Super-FRS local cryogenics. In order to reach a reasonable cooldown time of 3 to 4 weeks, it turned out during the cooldown calculation that a cooling power for Super-FRS cooldown will be of similar capacity as for the large ATLAS detector at CERN, the largest particle detector ever been built in the world (with the cooldown enthalpy about 121 GJ from 300 K to 4.5 K for its 680 tons aluminium alloy cold mass) [1]. Cryogenic engineering tells that the precooling with LN2 is necessary for especially large cold mass since approximately \( \approx 80 \% \) of the cool down load is from 300K to 80K. The capacity of a LN2 precooler for Super-FRS cooldown is specified at around 76 kW, which is about 25% more than the maximum capacity for ATLAS cooldown at CERN. The comparison has been done in terms of the cooldown time predicted for the Super-FRS and needed for the ATLAS detector to reach 4.5 K operation states.

CERN Magnet Testing

In the five meetings in series since May, 2013 at CERN and at GSI with regards to the Super-FRS magnet testing, the cryogenic group CSCY has provided substantial supports in the planning of the cryogenic facility for the testing at CERN in terms of magnet cooldown / warmup limitations, LN2 precooler cooling power estimation, operation conditions, interface definition, and magnet cryostat protection against over-pressure (under different worst-case scenarios, i.e., quench and insulation vacuum loss to air), and corresponding safety device sizing and set pressure choice according to European Standards as well as the testing programme about cryogenic measurement. The operation modes have been integrated into the flow scheme design of the feedboxes for different magnet groups and discussed with the experts from RIKEN in the fifth workshop on next generation Fragment Separator in Dec. 2013 in Japan. The operation experiences of the cryogenic and magnet system in the Big-RIPS at RIKEN would help us to determine certain important operation parameters both in magnet testing and in the machine commissioning phases, such as maximum allowed cooldown /warmup rates between 300 K and 100 K temperature range. The operation experience of the SAMURAI superconducting dipole at RIKEN and the design experience of the Cyclotron Gas Stopper under construction at MSU would help us to make reasonable decision for the local cryogenics of the CBM dipole to choose proper cooling technology, by a number of small cryo-coolers or over cryogenic distribution from large plant.

Local Cryogenics and Cryo Plant 1

The combination of the cryogenic distribution for low energy branch and for the high energy cave into one branch should ease the radiation protection design for the High Energy Cave construction. The updated cryogenic distribution branching into four sections over the branch box makes potential staging of the Super-FRS construction possible. The concept for the 3D engineering design of the feedboxes for all groups of magnets have been unified both for the group of 3 long multiplets located in front of the target area and the group of 3 short ones behind, and for the rest multiple groups as well. The 3D layout of the feedbox for dipole groups has been redone in order to fulfil the constraints at the bending sections of the tunnel. The space constraint due to the limited tunnel height in front of the target area has been eased with the updated installation concept of the safety valves on the multiplet. The DMU engineering check for the feedbox concept will be continuing under the new layouts in the target region and in the tunnel. The 3D layout of the cryogenic distribution transfer line in the Super-FRS tunnel and the buildings would be one of the next major tasks for 2014. In December 2013 a technical study was placed at two suppliers for refrigerators in order to get proposals for the best plant configuration in terms of shield cooling, 4 K cooling including liquifaction for the current leads and cool down. For this study the heat loads of the magnets and the local cryogenics were carefully rechecked and adapted to the present configuration. The output of the study is expected for April 2014 and will be the basis for the specifization of the cryo plant 1.

References
