Developments and results of Dry-Runs at the fragmentseparator FRS

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

Development

Motivation

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

Precycle procedure

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

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

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

Dry-run tests

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

Conclusion

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

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Experiment beamline: FRS
Experimentcollaboration:NUSTAR-Super-FRS-Experiments
Accelerator infrastructure: FRS
PSP: [2.4.19]
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Strategic university co-operation with: Darmstadt

Recent developments for controls at the superconducting fragmentseparator S-FRS in the LHC software architecture LSA

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

Motivation

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

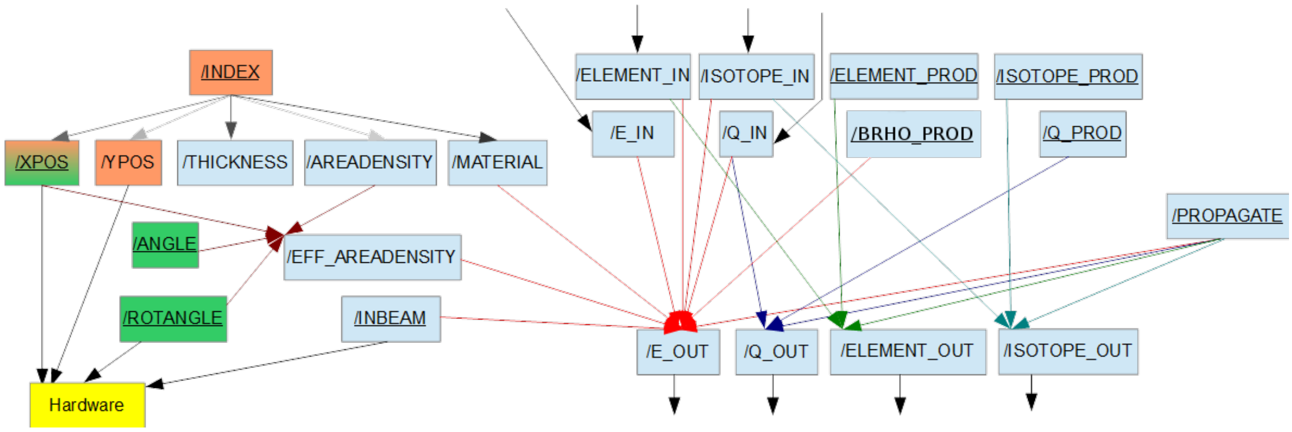

Figure 1: Updated Hierarchy for matter in FRS. Blue are parameters of the basic target hierarchy, which is further expanded depending on the type of matter being present. Orange representing targetladders and green degraders and degrader disks. Arrows of the same colour show relations between parameters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

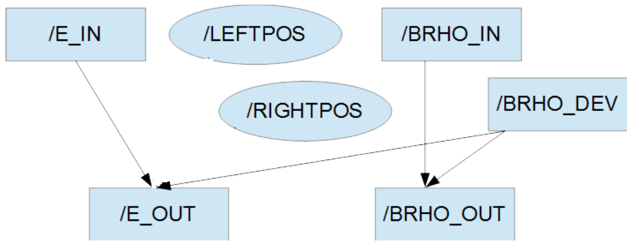

Figure 2: Hierarchy of a pair of horizontal slits. Position parameters are initial parameters and need to be set. Furthermore outgoing rigidity is determined by a deviation factor and incoming beam.

Slit modelling

Slits are being distinguished in the following 5 groups:

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

The group is mainly used for monitoring purposes, horizontal slits posses the ability of changing magnetic rigidity and beam energy. The individual separate slits and vertical slits are used to send set values to the hardware.

Propagation

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

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ferred. Instead these values have to be provided by a physicist outside of the control system via LISE++ [5] for example.

Conclusion

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

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Experimentcollaboration:
NUSTAR-SuperFRS-Experiments
Experiment proposal: none
Accelerator infrastructure: FRS
PSP codes: 2.4.0.2.
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Super-FRS design status report

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System design

The wide range of magnetic rigidity (Bρ) between 2-20 T·m of the Super-FRS requires the variation of the magnetic field B0 of the dipoles in the range 0.16-1.6 T. The upper third of that range is situated in a non-linear saturation region of the magnetization curve B(H), which leads to shortening of the effective length of the dipole field and the change of the field distribution with increasing current I. We have analyzed these effects for one of the 11^0-bend normal-conducting dipoles of the Pre-Separator. At present, a 3D field distribution from finite-element calculations is used for different excitation currents and a resulting Bρ(I), but in the future the measured field will be used. From the fields the high order Taylor transfer maps for the particles are obtained using DA techniques (COSY-infinity).

Magnets

SC multiplets

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

Figure 1: FoS short multiplet manufacturing: quadrupole and sextupoe coils (upper left panel), sextupole yoke assembly (upper right pael), thermal shield (lower left pannel), and vacuum vessel (lower right panel).

SC dipoles

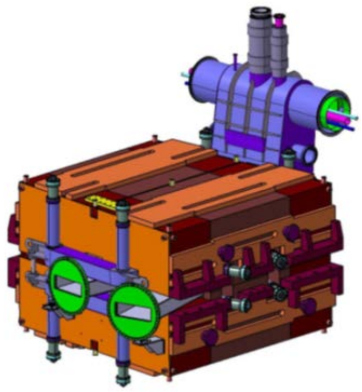

Figure 2: 3D model of the SC branching dipole magnet with additional straight beam exit.

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

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

Magnet test facility

The assembly of the technical infrastructures of the testing facility for SC magnets at CERN is mostly finalised (Figure 3) and the commissioning of the cryogenic

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system is under way. It is expected that the remaining work will be finalized until early summer 2018 to be ready for the cold test of the FoS short SC multiplet. As an important step also the contract amendment for the operating phase of the test facility has been closed.

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

Local cryogenics

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

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

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

Beam instrumentation

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

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

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

Target area / handling system

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

Figure 4: 1:1 mock-up of the target wheel plug during insertion test in a dummy chamber.

Beam catcher

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

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Accelerator infrastructure: Super-FRS
PSP codes: 2.4

Low cost interface for remote handling of insertions at the Super-FRS

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

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

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

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

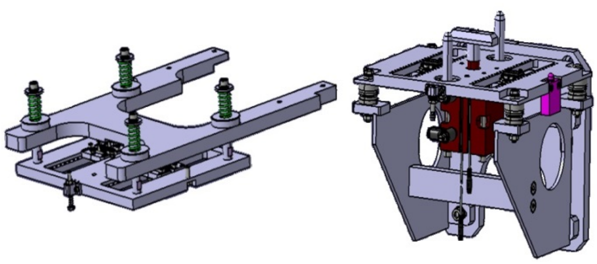

Figure 1: CAD drawings upper part (left) and lower part (right) of the media board including supports

One plate is mounted to the vacuum chamber and the other one to the insertion (drive flange). The plate which is fixed at the vacuum chamber includes the coupling actuator (pneumatic cylinder) and its connectors are wired to the DAQ equipment located in the supply-tunnel and niches of Super-FRS.

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

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

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

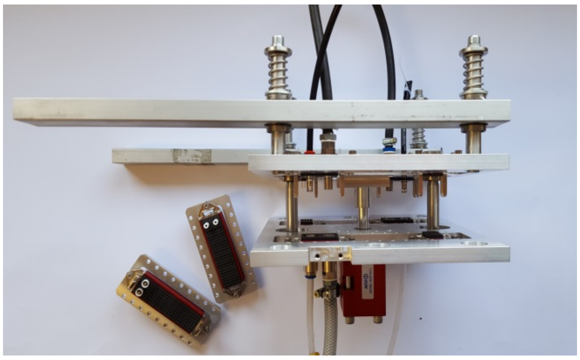

Figure 2: Media board prototype

In case of malfunctioning interlocks are sent to interrupt the connecting procedure.

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Accelerator infrastructure: Super-FRS
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Design verification tests of the Super-FRS slit system

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

The Super-FRS slit system is used to cut and collimate the ion beams in one transversal direction (horizontal or vertical) to the beam axis. The slit system consists of 15 slit-pairs, 9 horizontal (X-slit) and 6 vertical (Y-slit). Each slit contains two identical stopping blocks made of DENSIMET® (96% tungsten, 3% nickel and 1% iron), moveable transversal to the beam direction and operated in vacuum. This block material was chosen especially because of its high stopping power and heat resistance. The block sizes match the beam envelopes and can stop up to ^{12}C ions at 18 Tm.

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

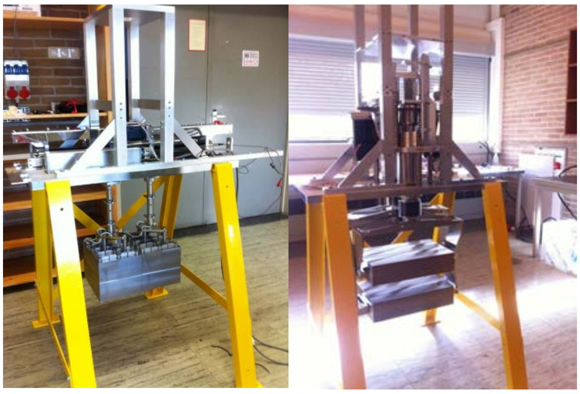

Figure 1: X-slit first of series of Super-FRS X- (left panel) and Y-slits (right panel).

Vacuum tests

Vacuum tests demonstrated that an ultimate pressure of 10^{-7} mbar could be obtained and that an integral leakage rate lower than10^{-9} mbar·l/s was achieved.

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

Motion tests

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

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

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

Beam absorption tests

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

Hook test

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

Outlook

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

References

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Accelerator infrastructure: Super-FRS
PSP codes: 2.4.6.2.3

Tests of a SEETRAM prototype for the Super-FRS

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

Introduction

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

The tested SEETRAM prototype was designed and manufactured at GSI [1]. It consisted of three circular aluminum foils, with thicknesses of 24 µm and diameter of 107 mm, each placed 5 mm apart. In order to verify the functionality of the prototype a test experiment had been carried out at the LNS in Catania (Italy). For this purpose a cyclotron ^{12}C beam at 62 MeV/nucl. had been used. The test aimed at i) demonstrating the proportionality between the measured intensity recorded by SEETRAM and diamond detector and ii) verifying the precision of a direct calibration of the prototype using light ions at 10^5 – 10^6 ions/s.

Setup of the experiment

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

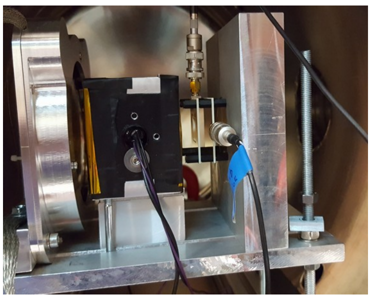

Figure 1: Setup, from right side: collimator, diamond detectors, plastic SCI and SEETRAM.

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

Results

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

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

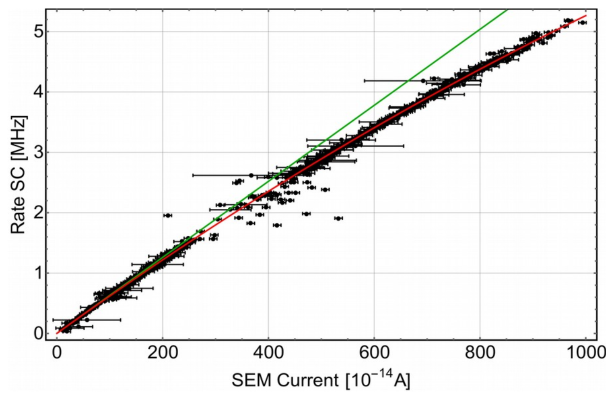

Figure 2: Calibration curve between SEETRAM and SC.

Outlook

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

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