MODIFICATIONS OF THE HIGH-ENERGY BEAM TRANSPORT AT GSI AND ITS SUBSYSTEMS FOR FAIR

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Abstract

The High-Energy Beam Transport at GSI (GSI-HEBT) is a system of transfer lines which delivers heavy ion beams from the SIS18 synchrotron to various experiments, the fragment separator and the storage rings ESR and CRYRING@ESR. The High-Energy Beam Transport for FAIR (FAIR-HEBT) will also branch off from the GSI-HEBT. This connection is currently under construction and requires several modifications in the GSI-HEBT to accommodate FAIR beamline devices within tight space constraints. Furthermore, FAIR will be operated from a new, fully digital control room. Therefore, all remaining analog devices of GSI-HEBT had to be digitized, in particular the cameras of the scintillating screens and the fast current transformers. The power converters for the magnets in GSI-HEBT, which are needed for beam transport to FAIR, are currently being upgraded to FAIR standard. These modifications of GSI-HEBT will be discussed in this paper in detail.

INTRODUCTION

The GSI Helmholtz Centre for Heavy Ion Research in Darmstadt, Germany operates an accelerator complex providing ion beams ranging from protons to uranium. The facility comprises the UNILAC linear accelerator, the SIS18 synchrotron, the fragment separator FRS, and the storage rings ESR and CRYRING@ESR. Experiments can be performed in several experimental areas located at different positions along the accelerator chain. The experimental caves downstream of SIS18, the FRS, and the storage rings are supplied with beam via a complex system of beam transfer lines known as the GSI High-Energy Beam Transport (GSI-HEBT).

The Facility for Antiproton and Ion Research (FAIR) is currently under construction as an extension of the GSI accelerator complex [1,2]. It will use the existing UNILAC and SIS18 of GSI as an injector and will include a new superconducting heavy-ion synchrotron (SIS100), a superconducting fragment separator (SFRS), and several new experimental areas. FAIR will be connected to the GSI-HEBT via the FAIR High-Energy Beam Transport (FAIR-HEBT). For the connection and operation of FAIR, several modifications and upgrades of the GSI-HEBT had to be implemented.

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FAIR CONNECTION

The new beamline towards FAIR (T1S1 line) branches off from the existing beamline serving the target hall and ESR (TE line) at the same location where the beamline to the FRS branches off. Consequently, the installation of the T1S1 line will lead to an extremely dense arrangement of beamline equipment in this area. In preparation for the FAIR connection, the originally installed two-way deflection magnet GTS1MU1 had already been replaced by a new three-way deflection magnet several years ago. Installation of the beamline components of the T1S1 line was scheduled for autumn 2025.

Issues and Collisions

Due to the very tight space constraints, the new beamline could only be designed with minimal mechanical clearances. The first quadrupole and the first main dipole magnet of the T1S1 line must be installed in close proximity to the existing TE line (Fig. 1). To avoid a collision with the beam pipe of the TE line, the first quadrupole had already been designed with a cutout in the iron yoke. The remaining clearance between these magnets and the beam pipe of the TE line was planned to be on the order of only 1 cm.

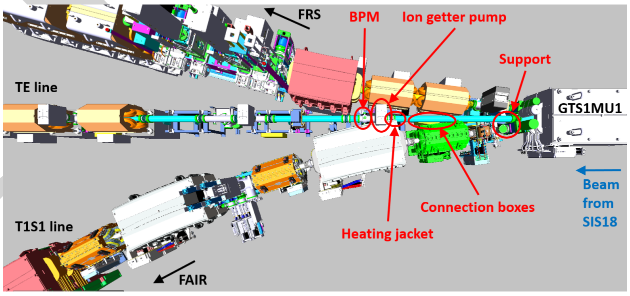

Figure 1: Old (planned) layout of the branching point area showing the existing beamlines to FRS and ESR/target hall (TE line) and the planned T1S1 beamline to FAIR. Collisions are indicated with red circles.

Shortly before the start of installation, however, several collisions between T1S1 beamline components and equipment of the existing TE beamline were identified in the 3D model. In particular, the first main dipole magnet of the T1S1 line interfered with a beam position monitor (BPM), an ion getter pump, and bake-out jackets of the beam pipe of the TE line. Additional conflicts were detected between supports of the T1S1 line and the connection boxes of the bake-out system, as well as with other supports belonging to the existing beamlines (Fig. 1).

Modifications of the TE Line

Resolving these issues exclusively on the side of the new beamline was not feasible, since the magnets had already been manufactured and their positions were constrained by the tunnel geometry. Consequently, modifications to the TE beamline were required.

The BPM was therefore relocated downstream, while the pumping chamber containing the ion getter pump was moved into the gap between the first quadrupole and dipole magnets of the T1S1 line (Fig. 2). To resolve the collision between the dipole magnet and the heating jacket, one of the magnet clamps had to be redesigned and rebuilt. Furthermore, the baked vacuum sector of the TE line was shortened by installing an additional gate valve upstream of the relocated pumping chamber. The new sector downstream of this valve will be unbaked, which allowed the removal of the heating jacket at the critical bottleneck.

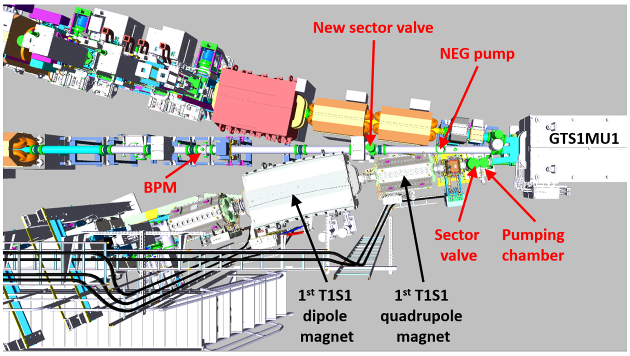

Figure 2: New layout of the branching point area indicating the new positions of relocated equipment and the new sector valve in red color.

The shortening of the baked sector is not expected to negatively affect the vacuum conditions of the SIS18, since the vacuum sectors of the FRS and FAIR beamlines starting directly downstream of GTS1MU1 are also unbaked. Nevertheless, a non-evaporable getter (NEG) pump was added to the shortened baked sector as an additional precaution. As a consequence of this vacuum system modification, the vacuum chamber originally used for the initial pump-down of the baked sector is no longer part of that sector. Therefore, the first vacuum chamber of the T1S1 line, located directly downstream of the sector valve, will change the position with the sector valve and will be used in the future for initial pump-down of the baked sector of the TE line. This redesign of the vacuum system required the fabrication of new vacuum pipes and supports, the procurement of heating jackets, the installation of an additional vacuum gauge, and an adaptation of the vacuum control system.

To resolve the collisions between the supports of the T1S1 line and the connection boxes of the bake-out equipment of the TE line, the electrical part of the bake-out system was rebuilt at a new position using new FAIR-type connection boxes. The cabling of the existing heating jackets was adapted accordingly and the new heating jackets will be integrated into the system. Furthermore, the first support in the T1S1 line had to be modified to eliminate a collision with an existing support. The resulting layout of the area is shown in Fig. 2. Work on the TE beamline started in October 2025 and is expected to be completed in the second quarter of 2026. The installation of the components of the T1S1 beamline has started with the first dipole magnet and continued in downstream direction. The missing beamline elements in the gap between GTS1MU1 and the first T1S1 dipole magnet will be installed once the work on the TE line is completed.

DIGITIZATION OF BEAM DIAGNOSTICS

The accelerator complex of GSI and FAIR will in the future be operated from a new control room located in the FAIR Control Center (FCC) [3], which is currently being commissioned [4]. This control room is fully digital without analog signal links to the accelerator subsystems. Therefore, all remaining analog accelerator components must be digitized prior to the relocation of the control room. For GSI-HEBT this mainly affects a substantial number of cameras used in scintillation screen stations and the fast current transformers (FCTs) (Fig. 3). An upgrade project to digitize these devices was initiated in 2023.

Upgrade of Scintillation Screen Stations

Scintillation screens are essential diagnostic devices for measuring the beam position and beam profile during beam set-up. The upgrade to digital cameras is required not only for operation from the FCC but also because the availability of spare parts is becoming increasingly limited due to the disappearance of analog cameras from the market.

The upgrade includes the replacement of analog with digital CMOS cameras (model IDS uEye UI-5240SE-M-GL) and their integration into the CUPID system (Control Unit for Profile and Image Data) [5]. In addition, the mechanical components, in particular the pneumatic drives, are being renewed (Fig. 4). The diagnostic vacuum chambers are also being modified to include fiducials that enable precise adjustment of the screens. Hence, this modification is expected to improve the accuracy of the beam position measurements.

At some locations, the radiation level during beam operation requires the usage of radiation hardened CID cameras (model Thermo Fisher MegaRAD3), which are analog. Since suitable digital alternatives are currently not available, their signals have been digitized using frame grabbers and integrated into the CUPID system as well.

Within the scope of this project, a total of 13 analog cameras are being replaced with digital cameras, while the signals of four radiation-hard analog cameras are being digitized. At the time of writing, only one camera remains to be upgraded, and completion of the project is expected by summer this year. Additionally, the installation of a further scintillation screen station is planned at a later stage in a beamline section that is currently insufficiently equipped with diagnostics.

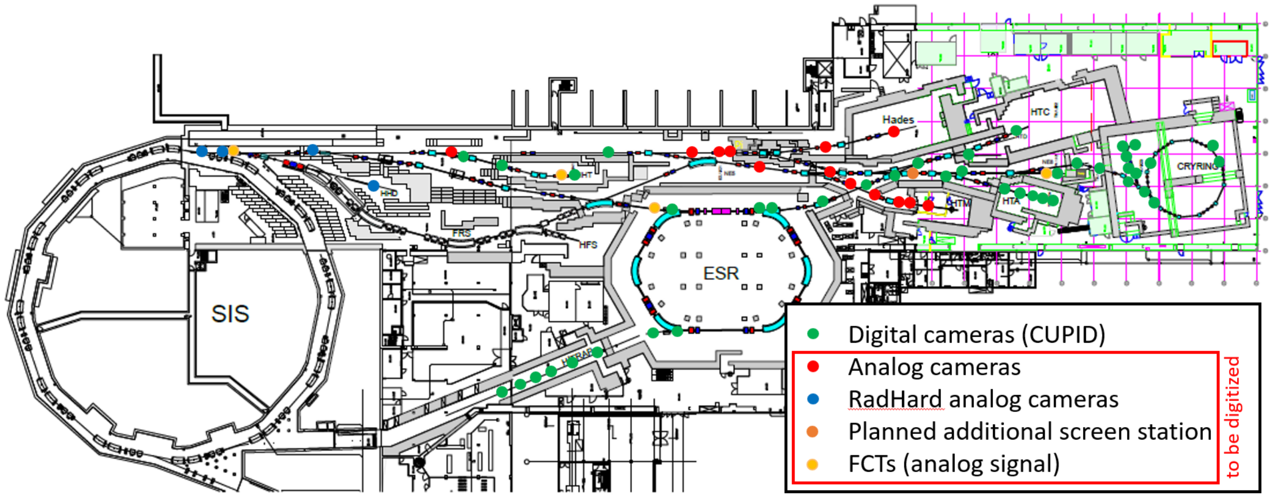

Figure 3: Plan of GSI-HEBT with the positions of the scintillation screen stations with digital, analog, and radiation hard analog cameras indicated in different colors as of the beginning of 2023. The positions of the FCTs are also shown.

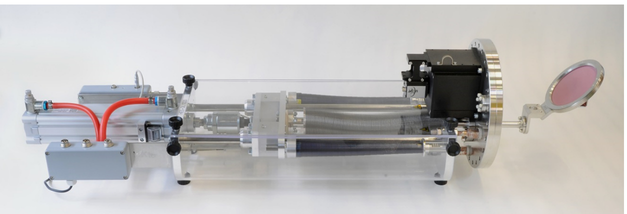

Figure 4: Example of a pneumatic drive for a scintillating screen, which was adapted for digital camera.

Fast Current Transformers

For the measurement of beam currents of fast-extracted beams, four FCTs are installed in the GSI-HEBT (Fig. 3). These devices provide analog output signals, which were previously recorded using an oscilloscope in the former control room. For operation from the FCC, these signals must be digitized.

To allow the development of the new data acquisition (DAQ) system for the FCTs without interfering with routine beam operation, the signals were split: one branch continues to be transmitted to the original control room, while the other is routed to a prototype DAQ system. The μTCA system is equipped with a 2.5 GSa/s ADC (14 bit) and IO boards for the remote control of the modular front-end electronics. The front-end consists of an optional -(0–60) dB attenuator module and a (20–60) dB Femto DUPVA-1-60 amplifier which addresses the large dynamic range of the FCT output signals. Further, the FCT signal can be disconnected remotely at the front-end input and dumped in a 50 Ω resistor.

The objective is to fully integrate the DAQ into the accelerator control system, together with a dedicated control application, by the end of 2026. Digitized FCT signals will also enable continuous monitoring of beam transmission, which represents an important performance indicator for the GSI-HEBT. For the existing resonant transformers in GSI-HEBT, also a modernization with a new μTCA DAQ system is currently being carried out.

POWER CONVERTER REFURBISHMENT

The power converters used in the GSI-HEBT date back to the 1990s, and the occurrence of faults and failures has increased in recent years. Within the framework of the GSI accelerator roadmap, a refurbishment or replacement of the aging power converters is therefore planned over the next ten years [6]. As an initial step, the power converters supplying the two quadrupole magnets and the one steerer magnet, that are required for beam transport from the SIS18 to the FAIR-HEBT, are currently being refurbished and upgraded to FAIR standards in order to improve their reliability for FAIR operation. Technically, the upgrade consists of a replacement of the main components in the power part, like dc-link capacitors, power electronics, output-filters, heatsinks and contactors as well as the installation of new digital FAIR-control units. Refurbishment of the two quadrupole power converters was completed in 2025, while their recommissioning and the upgrade of the steerer power converter is scheduled for 2026.

CONCLUSION AND OUTLOOK

Several modifications and upgrades of the GSI-HEBT for FAIR have been implemented or are currently in progress. These measures are required to establish the beamline connection to FAIR, to enable operation of the beam transport system from the new FAIR Control Center, and to ensure reliable beam delivery to FAIR. A large fraction of the work for these upgrades has already been completed, while the remaining work is expected to be finalized on schedule within the current year.

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