Development of integrated superconducting Quadrupole Doublet Modules for operation in the SIS100 accelerator


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Introduction to FAIR and SIS100

**Facility for Antiproton and Ion Research Project**
located at GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany

**SIS100 Synchrotron**
- Accelerator ring with a 6-fold symmetry
- Circumference: 1083.6 m
  12.5 m underground
- $B_\rho = 100$ Tm
Introduction to FAIR and SIS100

**SIS100 Structure**

- Lattice Cell DP-DP-QD-QF 12.9 m
- Extraction Module
- Straight Section of Sector 5
- Connection Box
- By-pass Line
- QP-Doublet Module (QDM)
- Arc Termination at Extraction in Sector 5
- QP-Magnets: $\frac{\partial B}{\partial t} = 58 \text{ (T/m)/s}$
  - $B_{\text{max}} = 27.8 \text{ T}$

**Segment structure**

- 3 stand alone QDMs of straight section type
- 9 QDMs of arc section type
- 2 QDMs of termination type
- 18 DP-Modules

**Beam direction**

- Straight Section Length: 51.6 m

**QDM: 2 QP-Units**

- QP-Magnets: $\frac{\partial B}{\partial t} = 58 \text{ (T/m)/s}$
  - $B_{\text{max}} = 27.8 \text{ T}$
Structure of SIS100 – Quadrupole Doublet Modules

**Typical assembly structure** (Arc section module, integration)

- Telescopic compensation bellow system
- Safety valves & blow-off guide
- Service port:
  - LCL ports
  - Instrumentation flanges
- Insulation vacuum vessel:
  - Vessel
  - Stiffening structure
  - Foot plates
  - Suspension domes
- Main thermal shield
- Service port shield:
  - Heat exchanger
  - Cooling collar
  - Cylindrical shield
- Interconnection shield
- Cold Mass:
  - 2 QP-units an bus bars
  - Cryogenic supply
  - Common girder
- Support feet
- Support frame
- Roughing cold-warm-transition
- Local current leads
Structure of SIS100 – Quadrupole Doublet Modules

- **Typical assembly structure** (Arc section module, cold mass)

![Diagram of a typical assembly structure](image)

- Common girder and Suspension
- Focusing QP-magnet (within unit)
- Steering magnet
- Cryo-catcher
- Roughing CWT
- Local current Leads
- Sextupole magnet
- Beam vacuum chamber, Defocusing QP-unit
- Load rod
- Tie rod
- Common girder
- Bus Bar system
- Beam position monitor
- Voltag breaker
- Bus bar system
- He-Supply and return, magnet cooling
- Beam vacuum chamber, Focusing QP-unit
- Defocusing QP-magnet (within unit)
### Configurations of SIS100-QDMs (Example: Type 2.4x)

<table>
<thead>
<tr>
<th>Unit Configuration</th>
<th>Doublet Configuration</th>
<th>Quantity</th>
<th>IOL-Cell</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upstream</td>
<td>Centre</td>
<td>Downstream</td>
<td>Joined Name</td>
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<tr>
<td>QDB   -TRP-</td>
<td>SF2</td>
<td>QDB-TRP-SF2</td>
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<tr>
<td>QDBb  -T-</td>
<td>SF2M</td>
<td>QDBb-T-SF2M</td>
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<td>SF2Mx</td>
<td>QDBx-T-SF2Mx</td>
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<tr>
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<td>SF1H</td>
<td>BQD-C-SF1H</td>
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<tr>
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<td>SF1B</td>
<td>VQD-CR-SF1B</td>
<td>1.7B</td>
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<tr>
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<td>BQD-C-SF2H</td>
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<tr>
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<td>SF1Bb</td>
<td>MQD-C-SF1Bb</td>
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<tr>
<td>MQDi   -C-</td>
<td>SF1Bi</td>
<td>MQDi-C-SF1Bi</td>
<td>1.Ei</td>
</tr>
</tbody>
</table>

**Abbreviations**

- **QD**: Defocusing quadrupole
- **F1**: Focusing quad. 1
- **F2**: Focusing quad. 2
- **B**: Beam position monitor
- **V**: Vertical chrom. sextupole
- **H**: Horizontal chrom. sextupole
- **S**: Steering magnet
- **M**: Multipole corrector magnet
- **C**: Cryo-ion-catcher (collimator)
- **T**: Drift tube
- **b**: modified busbars
- **i**: injection Y cryostat
- **x**: extraction Y cryostat
- **s**: Star shape chamber
- **P**: Cryo-sorption-pump
- **R**: Roughing pump with CWT

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Structure of SIS100 – Quadrupole Doublet Modules

Extraction module cold mass

Integrated QDM

QDBx-T-SF2Mx and extraction branch
Mechanical calculation results and cryogenic cooling solution

- **Displacement of magnet axis** (Arc section module, type 2.5)

Distance on beam axis, Z [mm]

![Graph showing displacement of magnet axis](image)

- Results of FEM engineering calculation
- Ion-optical axis are to be aligned one another
- Different pre-stress in US- and DS position to equalize overall tilt
- Evaluation of displacement along the ion-optical axis of the QDM
- Difference in displacement between RT and 4K-operation appears as negligible
- Pre-compensating offset of -0.9 mm is required
- Horizontal displacement below 10µm
- Displacement of fiducial target seats is expected to be less than 20 µm
**Cryogenic cooling solution**

Cooling scheme of SIS100 arc (right side figure)
- DP and QD - modules connected in parallel
- common He-supply: sub-cooled LHe: $T_1=4.5$ to $4.6$ K, $p=1.5$ to $1.6$ bar(a)
- Point 2, 2-phase He: $T_2 = T_3 = 4.3$ to $4.4$ K, $p_2=p_3=1.1$ to $1.2$ bar(a)
- Point 3: 2-phase or vapour, depending of SIS100 operation mode
- Point 2-2': Re-cooler

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QDM cooling scheme (Arc section module, left side figure):
- two parallel flow channels (M1, M2)
- Corrector magnets in series with QP-magnets
- common girder in series
- separate supply of vacuum chambers and cryo-catcher (V)
- flow restrictors at inlet of cooling channels
- hydraulic resistance to be tuned for fitting QP-units to each other and to DP-units
Development and procurement of module integration

- **Development structure of module integration**

  - **Basic development of type 2.5 by GSI**
  - **Series development of remaining configurations by an engineering partner**
  - **Revision Process by GSI:**
    - Production ready design of all configurations

  - Released CAD-Model & drawings
  - CAD-Model & drawings
Development and procurement of module integration

- **Procurement structure of module integration**

  ![Diagram of procurement structure]

  - **Integrator**
    - materials & components for module integration
    - Vacuum vessels
    - Telescopic bellows
    - Thermal shields
    - Common girders
    - Suspension systems
    - He-supply systems
    - Local current leads
    - Misc. small parts

  - **Test facility**
    - tested QP-Modules

  - **FAIR site**
    - **Module Integration**
      - QP - Modules

  - **GSI** → **JINR**
    - VC - Supplier
      - Beam vacuum chambers
    - BPM - Supplier
      - Beam position monitor
    - COL - Supplier
      - Cryo collimator
    - **CAP - Supplier**
      - Cryo adsorption pump
    - **CWT - Supplier**
      - Roughing CWT
      - Beam pipe CWT
    - **Contractor (GSI)**
      - Voltage Breaker
      - T-Sensors
      - HTSC-Stacks

  **Development and procurement of module integration**

  **Procurement structure of module integration**

- **Materials & Components**
  - Iron sheet metal
  - Main magnet wire
  - Corrector magnet wire
  - Voltage breaker
  - Beam vacuum chambers
  - Beam position monitor
  - Cryo collimator
  - Cryo adsorption pump
  - Roughing CWT
  - Beam pipe CWT
  - Voltage Breaker
  - T-Sensors
  - HTSC-Stacks

- **Materials & Components for Module Integration**
  - Iron sheet metal
  - Main magnet wire
  - Corrector magnet wire
  - Voltage breaker
  - Beam vacuum chambers
  - Beam position monitor
  - Cryo adsorption pump
  - Roughing CWT
  - Beam pipe CWT
  - Voltage Breaker
  - T-Sensors
  - HTSC-Stacks

- **Suppliers**
  - VC - Supplier
  - BPM - Supplier
  - COL - Supplier
  - CAP - Supplier
  - CWT - Supplier
  - Contractor (GSI)
Summary

- The new and unique heavy ion accelerator SIS100 is built at FAIR with challenging requirements on QP-magnets.
- 83 Integrated Quadrupole doublet modules in 4 categories and 11 configurations with 2 special module types are currently in development.
- Stability requirements are expected to be met under operation conditions, by pre-compensating predictable displacements.
- Cooling concept based on 2-phase cooling with parallel cooling channels and is implemented in the QDM design.
- Tuning of flow resistance is needed, to fit units to each other and to the DP-modules.
- Design phase for manufacturing design is proceeding. A design review will be established at GSI.
- Procurement is distributed to multiple supplier. JINR delivers the core components, QP-units with correctors.
- An integrator shall build the cryostat system and assemble the whole modules.
- The testing will be performed at an dedicated test facility prior to final tunnel installation.
Thank you very much for your interest and your kind attention!

Jan Patrick Meier

The PBMT – Team for FAIR@GSI:

& GSI-department ENMD