Document Title	**Detailed Specification for SIS100 Quadrupole Units Production**
Description	This document is the detailed specification of the SIS100 quadrupole unit production
Division/ Organization	GSI, SIS18/100, SCM
Field of Application	Project FAIR at GSI

Document History

Version	Prepared/Checked by	Date	Date of Release	Comments
V001	K. Sugita	14.07.2023		First Draft
V002	SCM	18.08.2023		Second Draft

e controlled

EDMS **2913884 v.1** status **Released** access **Restricted**
F-DS-SCM-en-MT_0152_Specification_for_SIS100_quadrupole_unit_production-V002_docx_cpdf.pdf modified **2023-08-18 11:02**

Abstract

(PSP 2.8.2.14) This document is a detailed specification of the Quadrupole Units for the heavy ion synchrotron SIS100. The Quadrupole Units are integrated in the SIS100 quadrupole doublet modules and installed in the SIS100 accelerator ring. There are several types for upstream as well as downstream units. Main element of the Units is the SIS100 quadrupole magnet. The quadrupole magnet is equipped with other components such as one or two corrector magnets, busbars, helium process pipes, operated at cryogenic temperature in insulation vacuum of the SIS100 quadrupole doublet module cryostat. This document describes the full scope of the quadrupole units and the low current quadrupole magnets required for SIS100. From this specification, a relevant contract defines the contents and the items that shall be delivered.

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1. Purpose and Classification of the Document

This document is a detailed specification of the SIS100 Quadrupole Units. This document specifies technical requirements of the Units. This document is the most detailed document in hierarchy to specify all rules and information for planned technical realization of the Units.

The general regulations and requirements are specified in the General Specifications [F-GS-PMO-en], Technical Guidelines, and Common and Detailed Specifications related to the units. They are only referenced in the present document. The related documents are listed in the chapter “Related Documents”.

The pictures in this document are for information only. Relevant dimensions and tolerances are specified in the corresponding drawings.

The article Identification (AID) number for produced units are:

SIS100 QPU Type VQD (b)	AID:0003821
SIS100 QPU Type SF2B (b)	AID:0003822
SIS100 QPU Type BQD (b)	AID:0003823
SIS100 QPU Type MQD (b)	AID:0003824
SIS100 QPU Type MQDi (b)	AID:0003825
SIS100 QPU Type QDB (b)	AID:0003826
SIS100 QPU Type QDBb (b)	AID:0003827
SIS100 QPU Type QDBx (b)	AID:0003828
SIS100 QPU Type SF1B (b)	AID:0003829
SIS100 QPU Type SF1Bb (b)	AID:0003830
SIS100 QPU Type SF1Bi (b)	AID:0003831
SIS100 QPU Type SF1H (b)	AID:0003832
SIS100 QPU Type SF2 (b)	AID:0003833
SIS100 QPU Type SF2H (b)	AID:0003834
SIS100 QPU Type SF2J (b)	AID:0003835
SIS100 QPU Type SF2M (b)	AID:0003836
SIS100 QPU Type SF2Mx (b)	AID:0003837

2. Abbreviations, Terms and Definitions

CID	Component ID
DS	Detailed Specification
FAIR	Facility for Antiproton and Ion Research
FAT	Factory Acceptance Test
FDR	Final Design Review
GS	General Specification
GSI	Helmholtzzentrum für Schwerionenforschung GmbH
HV	High Voltage
LV	Low Voltage
SAT	Site Acceptance Test
SIS100	Schwer-Ionen-Synchrotron 100 (Heavy-Ion-Synchrotron)
SC	Superconductor/Superconducting

3. Scope of the Technical System

3.1. System Overview

The SIS100 quadrupole unit is an assembly of the SIS100 main quadrupole magnet, one or two corrector magnets, and accompanying parts like bus-bars, helium process pipes, and instrumentation. There are upstream and downstream units, which will be integrated together into cryogenic quadrupole doublet modules (QDMs) for SIS100 in a later production process.

There are 7 types of upstream units and 10 types of downstream units. These are assembled to 9 standard QDMs and 3 special QDMs (for injection, extraction, and high radiation areas). As elements of the units, there are the following superconducting magnets: main quadrupole magnet, chromaticity sextupole magnet, steering magnet, multipole corrector magnet. A normal-conducting gamma-t jump quadrupole magnet is integrated into one of the unit types. In addition, for the injection and extraction QDMs, 4 superconducting low current quadrupole magnets are required.

The units are operated in an insulation vacuum under cryogenic temperature, which is achieved with two-phase helium flow. Due to related high pressure conditions, the units shall be manufactured with the relevant norms and standards compliant.

The scope of the specification in hand contains the unit design, production preparation and execution, quality controls and Factory Acceptance Test (FAT) with defined criteria, and transport of the accepted units. In addition, criteria of the Site Acceptance Test (SAT) is provided by the Company for information. The units will be subjected to a cold test in a dedicated test cryostat as a part of the SAT. Therefore, the interfaces should be adapted to the test cryostat. The condition (e.g. length) may be different from the interface to the QDM and need to be agreed in the Final Design Review (FDR) of the unit type. The execution of site acceptance test (SAT) is not scope of the specification nor scope of the Contractor's task.

3.2. Scope of Delivery

The deliverables are generally listed below. Further information is given in the relevant contract. The terms concerning delivery, providing or stocking by the contractor will be regulated in the commercial part of the relevant contract.

- **Scope of tasks by the contractor**

The following tasks shall be done by the Contractor:

- Approval of the manufacturing design provided by GSI
- Plausibility check of the functionality of the units
- In case of modification of the design, the Contractor issues an Engineering Change Request (ECR) for approval by the Company.
- Procurement of raw materials and components except the ones which are supplied by the Company
- Procurement, installation, commissioning, and operation of tooling and devices for the production.
- Necessary manufacturing studies like test samples, simulations, test mock-ups
- Manufacturing of the units
- Inspection and quality control of the units
- Factory Acceptance Test (FAT) and issuing documentation, reporting
- Safe and timely transport of the units to GSI, Darmstadt, Germany (or GSI specified place)

The Contractor shall be responsible for the manufacturing of the units in accordance with the approved manufacturing drawings and work instructions. The Contractor is also responsible for verification of the mechanical design provided by GSI. Mechanical design changes are allowed in accordance with GSI procedures (an ECR needs to be issued). However, the functionality of the magnets and the units shall be kept.

- **Documents and information supplied from the Company to the Contractor**

- Detailed specification
- General specification
- Relevant specifications and technical guidelines
- Sets of drawings of the units and 3D models
- Work instructions
- List of the acceptance criteria for FAT
- List of the acceptance criteria for SAT (for information only)

Details of the status of the documents are summarized in Amendment 01 to this specification, *Amendment01_F-DS-SCM-en-MT_0152_Specification_for_SIS100_quadrupole_unit_production.*

- **Materials, parts, components supplied from the Company to the Contractor (sufficient amount for the deliverables)**
  - Electromagnetic steel sheets for lamination of the iron yoke
  - Superconducting wires
  - Voltage breakers
  - Temperature sensors
  - Cold terminals as part of local current leads for the corrector magnets
  - Assembled gamma-t jump quadrupole magnets (in case the units with the gamma-t jump quadrupole magnets will be produced)

The exact scope of the deliverables by the company is defined in the corresponding contract.

The contractor shall be able to store at least the supply by the Company needed for one year of production. The contractor shall inform the company at least two months before the supply of a deliverable ends.

Remaining materials must be sent back to the Company.

- **Documents and information submitted from the Contractor to the Company**

All documents issued by either side shall be exchanged solely via EDMS. Further details on structure and organization shall be agreed between the parties beforehand.

- **2 weeks before the Final Design Review of the Unit**

  The following documents shall be submitted at least 2 weeks before FDR for review of the Company:
  - Engineering change requests (ECR), if there are changes from the provided design
  - In case of an accepted ECR: updated drawings and 3D model of the units,
  - A set of drawings & 3D Models of the tooling and devices for the manufacturing, the transportation and storage (according to Technical Guideline Konstruktionsrichtlinie [F-TG-MDS-de-KRL])
  - Procurement plan for the materials
  - Quality inspection and production plan (QIPPs)
  - Work instructions if defined by the contractor
  - Template of test protocols with acceptance criteria
  - Welding plan and welding procedure specification (WPS)
  - Schedule of the production (Microsoft Project file or similar software file)
- **2 weeks before start of the unit production**
  - updated documents from previous list shall be submitted from the Company to the Contractor. Only after approval by the Company, the Contractor shall start the production.
- **every week during production**
  - Production progress report, in a standardized manner

- **Written Information after production of the Unit (FAT approval relevant)**
  - Quality inspection and production plan (filled and approved during the production)
  - Non conformity reports (if there are non-conformities detected.)
  - Relevant certificate of the materials for the units (e.g. AD 2000, European Pressure Equipment Directive)
  - Relevant documents according to the European Pressure Equipment Directive (and AD 2000)
  - Welding & brazing certificates
  - Work instruction for interconnections (information provided by the Company)
  - Declaration of conformity
  - Complete set of as-built drawings and 3D models

  The Contractor and the Company may agree stepwise, Module type by Module type (or Unit type by Unit type) on design review and production.

- **Products delivered from the Contractor to the Company**

Main deliverables are the Quadrupole Units for SIS100, both for standard QDMs and special QDMs. For all types, the exact numbers and types of units (subsets) to be delivered by the contractor are defined in the relevant contract. Pairs of the SIS100 Quadrupole Units for specific QDMs shall be manufactured and then delivered in one batch as a pair.

For an overview, the following Quadrupole Units for standard QDM types are required to realize SIS100. The quantities in the tables are just for information.

Table 1: Standard QDMs and Unit types

QDM type	Upstream unit type	Downstream unit type	Quantity (full SIS100)
2.123	QDB	SF2	14
2.4	QDBb	SF2M	5
2.5	VQD	SF2B	6
1.6A	BQD	SF2H	12
1.7B	VQD	SF1B	12
2.8C	BQD	SF2H	12
2.9D[1]	BQD	SF2J	12
1.E	MQD	SF1Bb	5
		total	78

[1] The module type 2.9D is elsewhere subdivided into 2.9 and 2.D, both containing identical unit types but differing in interconnections.

The following Quadrupole Units for special QDM types as well as low current quadrupole magnets are required for SIS100. The quantities in the tables are just for information.

Table 2: Special QDMs and Unit types

QDM type	Upstream unit type	Downstream unit type	Low current quadrupole	Quantity (full SIS100)
2.13s	QDB	SF2		3
2.4x	QDBx	SF2Mx	QS(x) + QS(x)	1
1.Ei	MQDi	SF1Bi	QS(i) + QS(i)	1
			total	5

In total 166 units (83 unit pairs) and 4 low current quadrupole magnets for 83 QDMs are required for SIS100.

In case spare units are contracted, the spare units shall be packaged in sets in stackable containers suitable for long term storage.

- **Tooling for production delivered from the Contractor to the Company**

Special dedicated tooling used for the production of the units must be stored at the Contractor or delivered to the Company in stackable packaging after the production. The packaging shall allow for long term storage without degradation of its contents. A list clearly identifying the content of the packaging shall be included and accessible without opening the package. The details and the contents shall be defined in the Contract.

3.3. Spare Parts

Spare units must be produced and delivered in accordance with the relevant Contract. Additional spare parts must be defined in the relevant contract.

4. System Specification

4.1. Overview

SIS100

The heavy ion synchrotron SIS100 is a workhorse accelerator in the FAIR accelerator complex. The accelerated particle beam is provided to experiment sites and further accelerator facilities. SIS100 is a superconducting magnet machine, cooled with two phase helium flow around 4.5 K. The ring has six-fold symmetry and each sector consists of 14 cells. Each cell contains one quadrupole doublet module (QDM). Cell 1, 2, 3 are in the straight section, cell 4 to 14 are in the arc section of the ring. (Figure 1)

SIS100 Quadrupole Doublet Module (QDM)

9 types of standard QDMs (Table 3) and 3 special modules at the injection, extraction, and high radiation region (Table 4) are foreseen. Each doublet consists of 2 Quadrupole Units mounted on a common girder. The quadrupole doublet cold mass is installed into a SIS100 quadrupole doublet cryostat by means of a suspension structure.

SIS100 Quadrupole Units

The quadrupole units are mechanical assemblies of one SIS100 main quadrupole magnet and one or two smaller magnets as well as busbars, helium process pipe, etc. This specification in hand describes all types of the units for all quadrupole doublet modules.

Table 3 shows the variety of the quadrupole units for all standard QDM types. The upstream units utilize the defocusing SIS100 quadrupole magnet (QD) as their core component. A chromaticity sextupole magnet (CV) or a multipole corrector magnet (MC) are attached to the front of the quadrupole magnet for VQD and MQD, respectively. The other QDB and BQD modules contain only one QD magnet and are having interfaces to the beam position monitor (BPM) with different directions. The BPM is not a part of the deliverables.

The focusing SIS100 quadrupole magnet (F1 or F2) is the core of the downstream units. It has to be connected in series to either the electrical circuit family 1 or 2, respectively. Always a steering magnet is attached to the front of the quadrupole magnet. A chromaticity sextupole magnet for SF1H and SF2H, a multipole corrector magnet for SF2M, a gamma-t jump quadrupole magnet for SF2J are attached at the rear of the quadrupole magnet. The gamma-t jump quadrupole magnets will be supplied by the Company to the Contractor and have to be attached. The beam position monitor (BPM) is not a part of the deliverables. It is mounted after unit production during QDM integration[2].

Table 4 shows the Special QDMs and their Unit configuration. In addition to the Units, 4 low current quadrupole magnets will be integrated for the injection module 1.Ei and the extraction module 2.4x.

[2] Note: the indication of a BPM in the nomenclature of the units (e.g. SF2B) is necessary to distinguish between different unit types. For instance, the unit SF2 is not identical to the unit SF2B in terms of busbar routing, helium tubing and further. Further unit types are affected by such differences.

For both standard and special modules, the units having an identical name for different QDMs are fully identically designed.[3] Therefore, there are 7 upstream unit types as well as 10 downstream unit types.

Figure 1 shows the overview of the SIS100 accelerator ring, the Quadrupole Doublet Modules and Units for the example of the 1.7B module type.

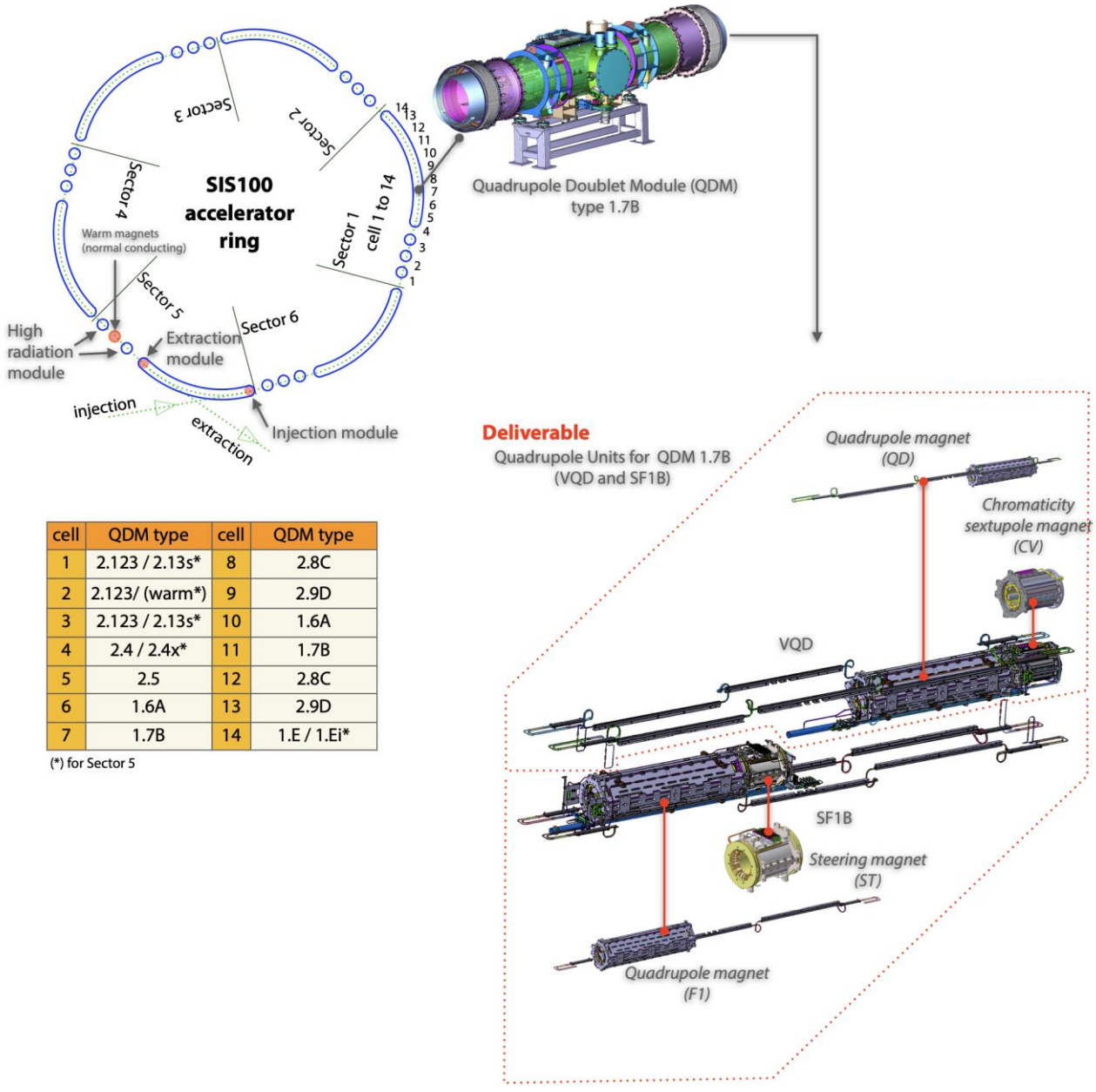
Table 3: Standard QDMs, Unit types, and the configuration (*italic* is not a part of the deliverable, QJ is provided by the Company)

QDM types	2.123	2.4	2.5	1.6A	1.7B	2.8C	2.9D	1.E
Upstream unit	QDB	QDBb	VQD	BQD	VQD	BQD	BQD	MQD
contents			**CV**	*BPM*	**CV**	*BPM*	*BPM*	**MC**
	QD	**QD**	**QD**	**QD**	**QD**	**QD**	**QD**	**QD**
	BPM	*BPM*						
Downstream unit	SF2	SF2M	SF2B	SF1H	SF1B	SF2H	SF2J	SF1Bb
contents	**ST**	**ST**	**ST**	**ST**	**ST**	**ST**	**ST**	**ST**
	F2	**F2**	**F2**	**F1**	**F1**	**F2**	**F2**	**F1**
		MC	*BPM*	**CH**	*BPM*	**CH**	**QJ**	*BPM*
Quantity	14	5	6	12	12	12	12	5

Table 4: Special QDMs, Unit types, and the configuration (*italic* is not a part of the deliverable).

QDM types	2.13s	2.4x		1.Ei	
Upstream unit	QDB	QDBx		MQDi	
contents				**MC**	
	QD	**QD**	**QS(x)**	**QD**	**QS(i)**
	BPM	*BPM*			
Downstream unit	SF2	SF2Mx		SF1Bi	
contents	**ST**	**ST**		**ST**	
	F2	**F2**	**QS(x)**	**F1**	**QS(i)**
		MC		*BPM*	
Quantity	3	1	1	1	1

[3] This statement is not true for the quadruple magnets as such. There are differences between the QD quadrupole in the straight-section units QDB and the QD quadrupole in the other upstream units, which are for the arc. Similarly, there are differences between the F2 quadrupole in the straight-section units SF2 and the F2 quadrupole in the other downstream units, which are for the arc.



cell	QDM type	cell	QDM type
1	2.123 / 2.13s*	8	2.8C
2	2.123/ (warm*)	9	2.9D
3	2.123 / 2.13s*	10	1.6A
4	2.4 / 2.4x*	11	1.7B
5	2.5	12	2.8C
6	1.6A	13	2.9D
7	1.7B	14	1.E / 1.Ei*

(*) for Sector 5

Figure 1: Overview of the SIS100 ring, QDMs, Quadrupole Units. Here only QDM type 1.7B is shown as an example. (SF1B without "B" = Beam Position Monitor is shown.)

4.2. Technical Requirements for System Components

The variation of the combination of the units for the QDMs is explained below. As the core elements of the units, the superconducting magnets are extensively described later sections. The busbars providing electric power, and the helium pipes supplying the coolant to the magnets as well as the instrumentation, which is crucial for the magnet operation controls are explained below and in the relevant specifications found in chapter 7.

4.2.1. Quadrupole Units for Quadrupole Doublet Modules

4.2.1.1. Quadrupole Units for QDM type 2.123 and 2.13s: QDB and SF2

The QDM type 2.123 as well as 2.13s is located at the beginning of the sectors of the SIS100 ring. These are standalone cryogenic modules next to room temperature accelerator components. Therefore, the modules have cryogenic, electrical, vacuum, and mechanical interfaces to a bypass line. The module consists of the QDB unit at upstream and the SF2 unit at downstream.

Figure 2 shows the units. QDB is the quadrupole magnet QD with a long busbar pair connection to the coil and with electrical joints to the bypass line. SF2 is an assembly of the quadrupole magnet F2 and the steering magnet ST. Unlike on all arc units, there are no extra transport busbars nor extra pipes as helium supply line.

In total 17 sets of this unit combination are required for SIS100.

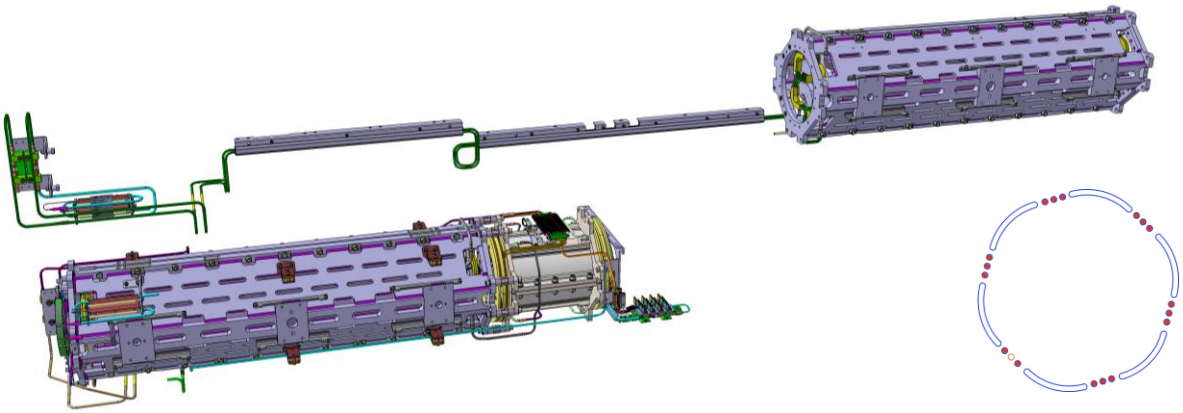


Figure 2: Quadrupole units QDB (top) and SF2 (bottom)

4.2.1.2. Quadrupole Units for QDM type 2.4: QDBb and SF2M

The QDM type 2.4 is located at the beginning of the arc of each sector (except sector 5) of the SIS100 ring. The module has interfaces to a bypass line as well as to dipoles. The module consists of the QDBb unit at upstream and the SF2M unit at downstream.

Figure 3 shows the relevant units. QDBb is an assembly of the quadrupole magnet QD with a long busbar pair connecting to the coil, and a pair of busbars for the SIS100 dipole magnet circuit. SF2M is an assembly of the quadrupole magnet F2, the steering magnet ST, the multipole corrector magnet MC. It is equipped with the busbar pair for supply of the F2 quadrupole and a busbar pair for the SIS100 quadrupole magnet circuit F1. The helium process pipes are equipped for both units.

In total 5 sets of this unit combination are required for SIS100.

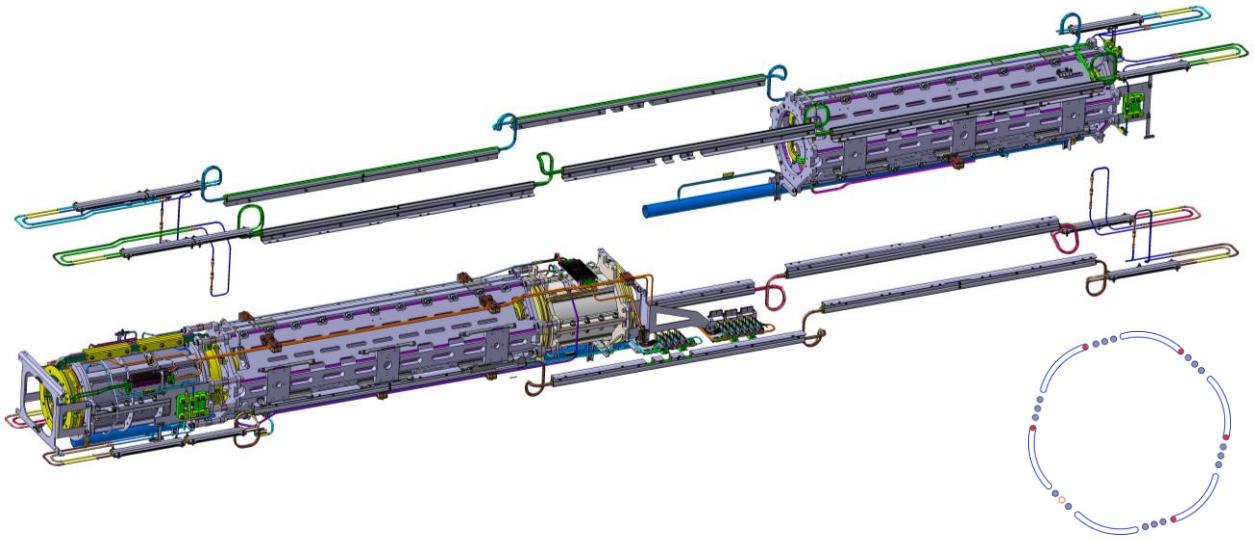


Figure 3: Quadrupole units QDBb (top) and SF2M (bottom)

4.2.1.3. Quadrupole Units and Low Current Quadrupole Magnets for QDM type 2.4x: QDBx, SF2Mx, QS(x)

The QDM type 2.4x is a cryogenic module for SIS100 extraction, located at the beginning of the arc of sector 5 of the SIS100 ring. The module has interfaces to a bypass line as well as to dipoles. The module consists of the QDBx unit at upstream and the SF2Mx unit at downstream, as well as 2 low current quadrupole magnets QS(x).

Figure 4 shows the relevant units. QDBx is an assembly of the quadrupole magnet QD with a long busbar pair connecting to the coil, and a pair of busbars for the SIS100 dipole magnet circuit. SF2Mx is an assembly of the quadrupole magnet F2, the steering magnet ST, the multipole corrector magnet MC. It is equipped with the busbar pair for supply of the F2 quadrupole and a busbar pair for the SIS100 quadrupole magnet circuit F1. The helium process pipes are equipped for both units. Figure 5 shows the low current (extraction) quadrupole and mechanical assembly and overview of the module 2.4x.

In total 1 set of this unit combination as well as two low current quadrupole magnets are required for SIS100.

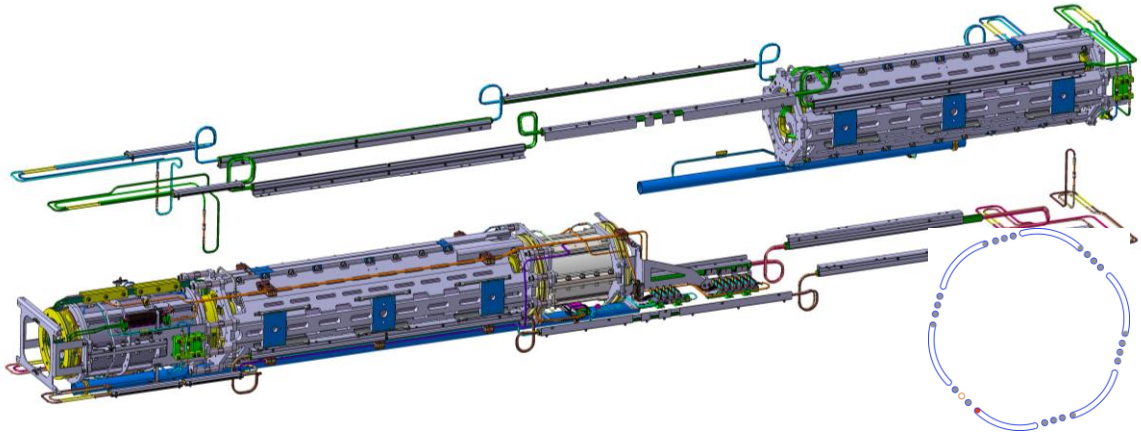


Figure 4: Quadrupole units QDBx (top) and SF2Mx (bottom)

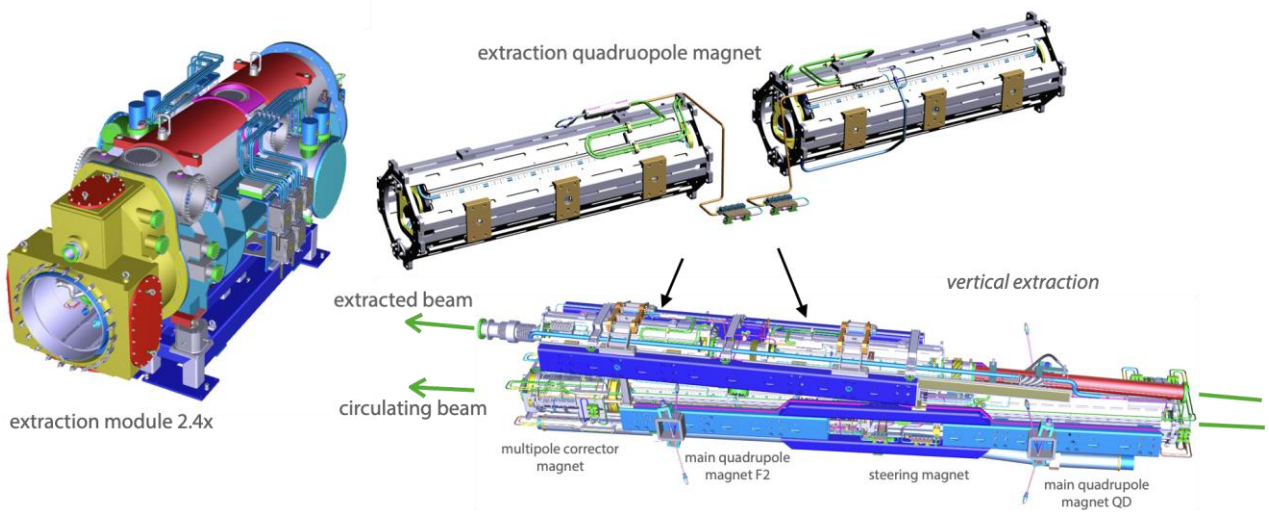


Figure 5: Low current quadrupole magnets and extraction module 2.4x

4.2.1.4. Quadrupole Units for QDM type 2.5: VQD and SF2B

The QDM type 2.5 is located in the arc section of each sector of the SIS100 ring. The module has interfaces to dipoles and missing dipoles. The module consists of the VQD unit at upstream and the SF2B unit at downstream.

Figure 6 shows the units. VQD is an assembly of the chromaticity sextupole magnet CV and the quadrupole magnet QD with a long busbar pair connecting to the coil, and a pair of busbars for the SIS100 dipole magnet circuit. SF2B is an assembly of the quadrupole magnet F2 and the steering magnet ST. It is equipped with the busbar pair for supply of the F2 quadrupole and a busbar pair for the SIS100 quadrupole magnet circuit F1. The helium process pipes are equipped for both units.

In total 6 sets of this unit combination are required for SIS100.

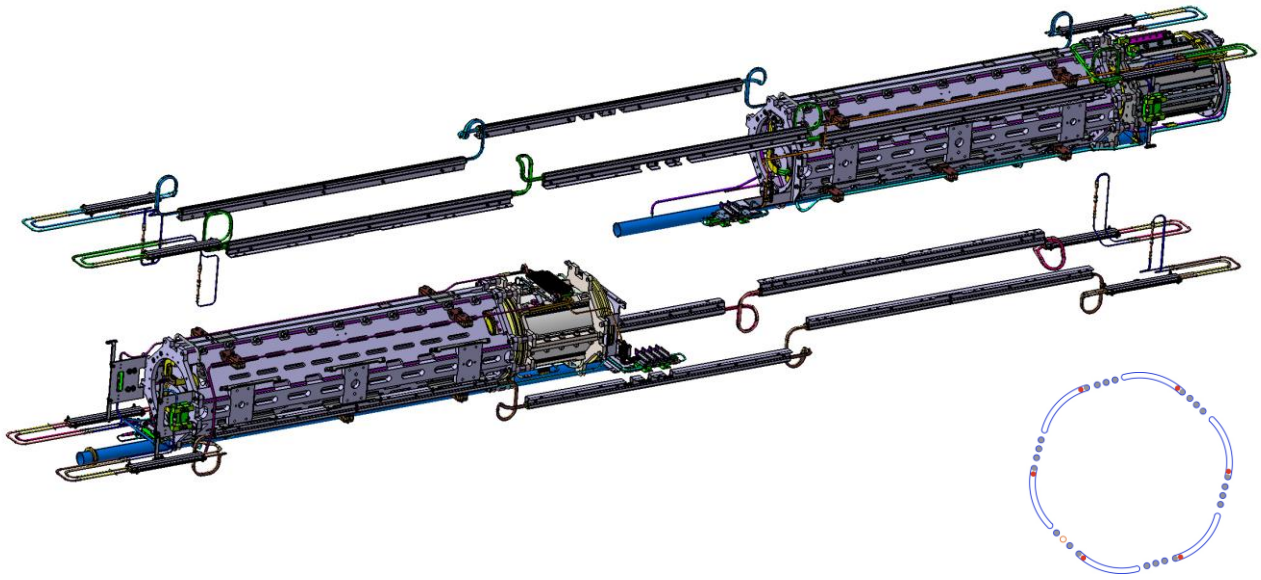


Figure 6: Quadrupole units VQD (top) and SF2B (bottom)

4.2.1.5. Quadrupole Units for QDM type 1.6A: BQD and SF1H

The QDM type 1.6A is located in the arc section of each sector of the SIS100 ring. The module has interfaces to dipoles. The module consists of the BQD unit at upstream and the SF1H unit at downstream.

Figure 7 shows the units. BQD is an assembly of the quadrupole magnet QD with a long busbar pair connecting to the coil, and a pair of busbars for the SIS100 dipole magnet circuit. SF1H is an assembly of the quadrupole magnet F1, the steering magnet ST, and the chromaticity sextupole CH. It is equipped with the busbar pair for supply of the F1 quadrupole and a busbar pair for the SIS100 quadrupole magnet circuit F2. The helium process pipes are equipped for both units.

In total 12 sets of this unit combination are required for SIS100.

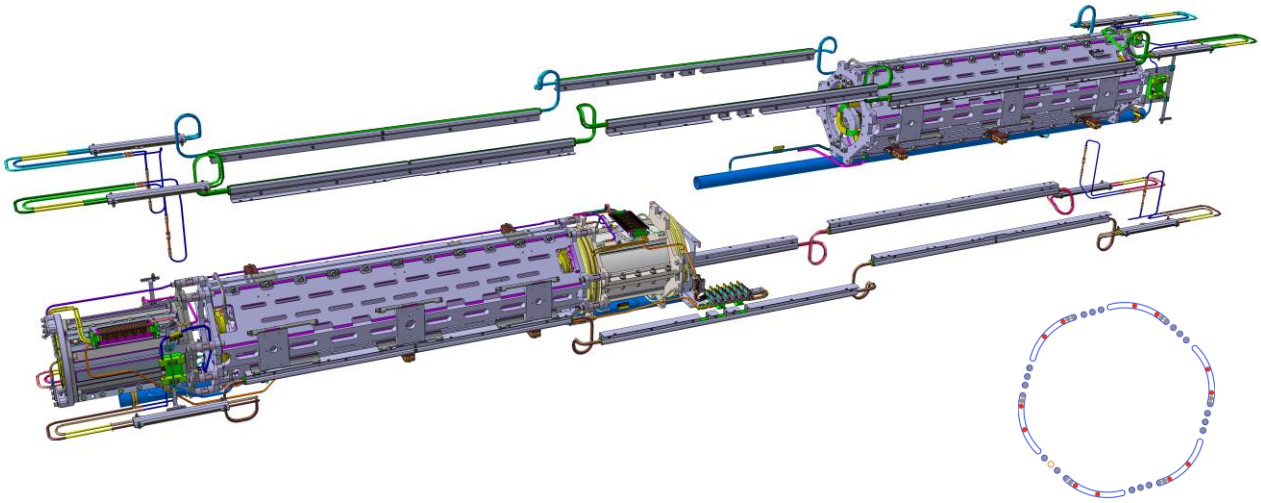


Figure 7: Quadrupole units BQD (top) and SF1H (bottom)

4.2.1.6. Quadrupole Units for QDM type 1.7B: VQD and SF1B

The QDM type 1.7B is located in the arc section of each sector of the SIS100 ring. The module has interfaces to dipoles. The module consists of the VQD unit at upstream and the SF1B unit at downstream.

Figure 8 shows the units. VQD is identical with VQD unit in QDM 2.5. SF1B is an assembly of the quadrupole magnet F1 and the steering magnet ST. It is equipped with the busbar pair for supply of the F1 quadrupole and a busbar pair for the SIS100 quadrupole magnet circuit F2. The helium process pipes are equipped for both units.

In total 12 sets of this unit combination are required for SIS100.

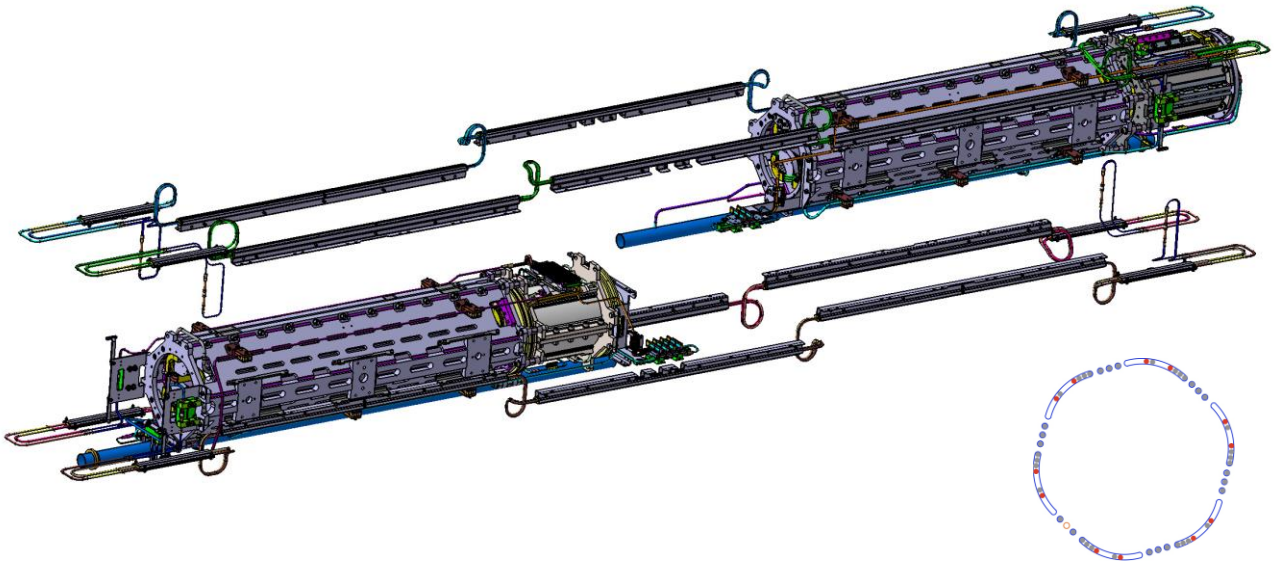


Figure 8: Quadrupole units VQD (top) and SF1B (bottom)

4.2.1.7. Quadrupole Units for QDM type 2.8C: BQD and SF2H

The QDM type 2.8C is located in the arc section of each sector of the SIS100 ring. The module has interfaces to dipoles. The module consists of the BQD unit at upstream and the SF2H unit at downstream.

Figure 9 shows the units. BQD is identical with BQD unit in QDM 1.6A. SF2H is an assembly of the quadrupole magnet F2, the steering magnet ST, and the chromaticity sextupole magnet CH. It is equipped with the busbar pair for supply of the F2 quadrupole and a busbar pair for the SIS100 quadrupole magnet circuit F1. The helium process pipes are equipped for both units.

In total 12 sets of this unit combination are required for SIS100.

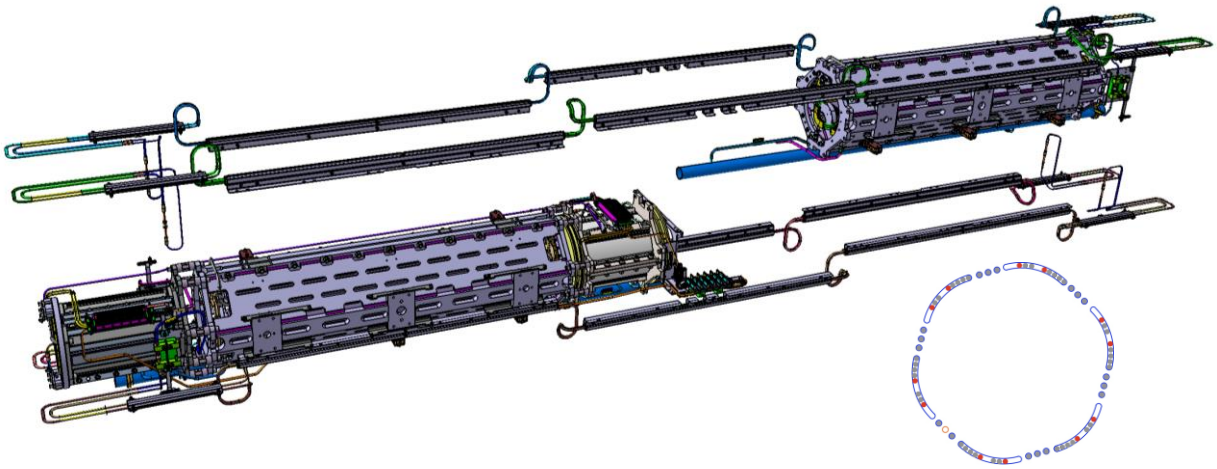


Figure 9: Quadrupole units BQD (top) and SF2H (bottom)

4.2.1.8. Quadrupole Units for QDM type 2.9D: BQD and SF2J

The QDM type 2.9D is located in the arc section of each sector of the SIS100 ring. The module has interfaces to dipoles and missing dipoles. The module consists of the BQD unit at upstream and the SF2J unit at downstream.

Figure 10 shows the units. BQD is identical with BQD unit in QDM 1.6A as well as in 2.8C. SF2J is an assembly of the quadrupole magnet F2, the steering magnet ST, and the gamma-t jump quadrupole magnet QJ (provided by the Company). It is equipped with the busbar pair for supply of the F2 quadrupole and a busbar pair for the SIS100 quadrupole magnet circuit F1. The helium process pipes are equipped for both units.

In total 12 sets of this unit combination are required for SIS100.

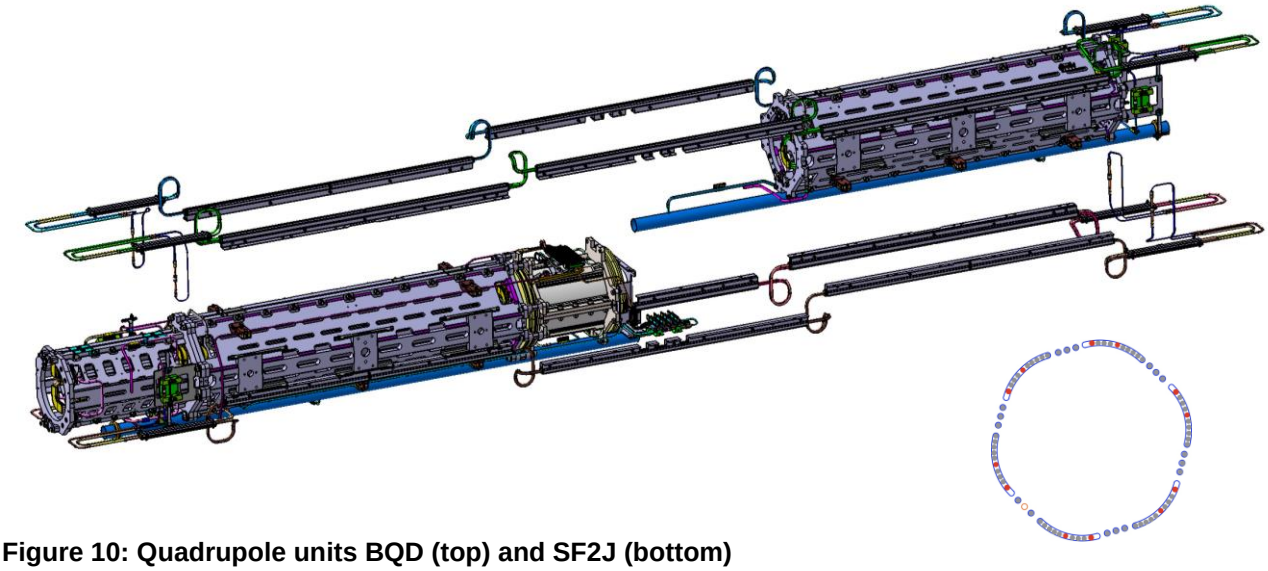


Figure 10: Quadrupole units BQD (top) and SF2J (bottom)

4.2.1.9. Quadrupole Units for QDM type 1.E: MQD and SF1Bb

The QDM type 1.E is located at the end of the arc section of each sector (except sector 5) of the SIS100 ring. The module has interfaces to a dipole and to the bypass line. The module consists of the MQD unit at upstream and the SF1Bb unit at downstream.

Figure 11 shows the units. MQD consists of the multipole corrector magnet MC and the quadrupole magnet F1 with a long busbar pair connecting to the coil, and a pair of busbars for the SIS100 dipole magnet circuit. SF1Bb is an assembly of the quadrupole magnet F1 and the steering magnet ST. It is equipped with the busbar pair for supply of the F1 quadrupole and a busbar pair for the SIS100 quadrupole magnet circuit F2. The helium process pipes are equipped for both units.

In total 5 sets of this unit combination are required for SIS100.

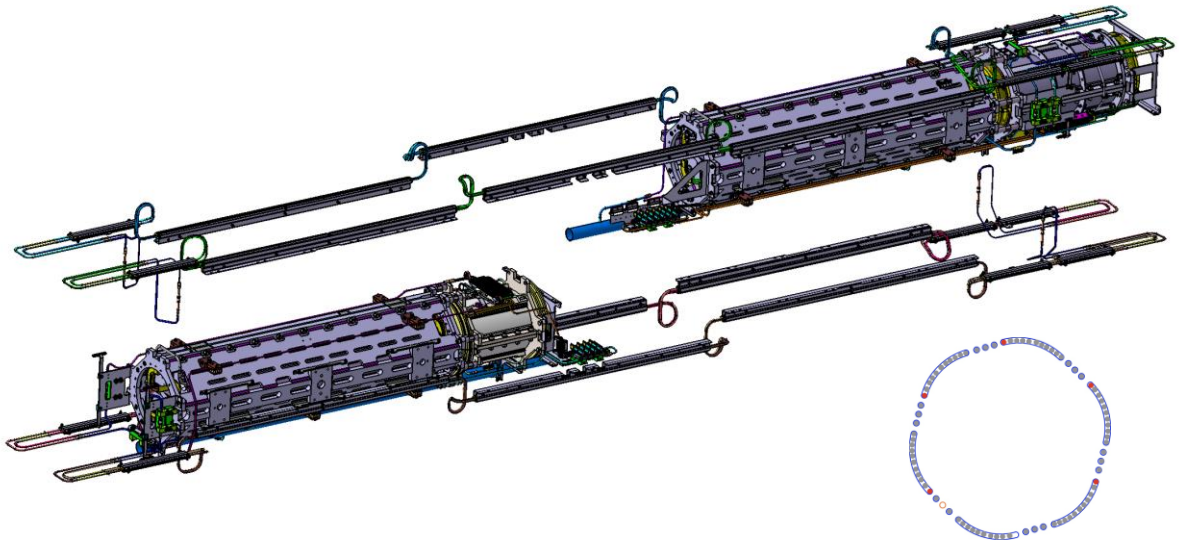


Figure 11: Quadrupole units MQD (top) and SF1Bb (bottom)

4.2.1.10. Quadrupole Units for QDM type 1.Ei: MQDi and SF1Bi

QDM type 1.Ei is a cryogenic module for SIS100 injection, located at the end of the arc section of sector 5 of the SIS100 ring. The module has interfaces to a dipole and to the bypass line. The module consists of the MQDi unit at upstream and the SF1Bi unit at downstream.

Figure 12 shows the units. MQDi consists of the multipole corrector magnet MC and the quadrupole magnet QD with a long busbar connecting to the coil, and a pair of busbars for the SIS100 dipole magnet circuit. SF1Bi is an assembly of the quadrupole magnet F1 and the steering magnet ST. It is equipped with the busbar pair for supply of the F1 quadrupole and a busbar pair for the SIS100 quadrupole magnet circuit F2. The helium process pipes are equipped for both units. Figure 13 shows the low current (injection) quadrupole magnets and mechanical assembly and overview of the module 1.Ei.

In total 1 set of this unit combination as well as two low current quadrupole magnets are required for SIS100.

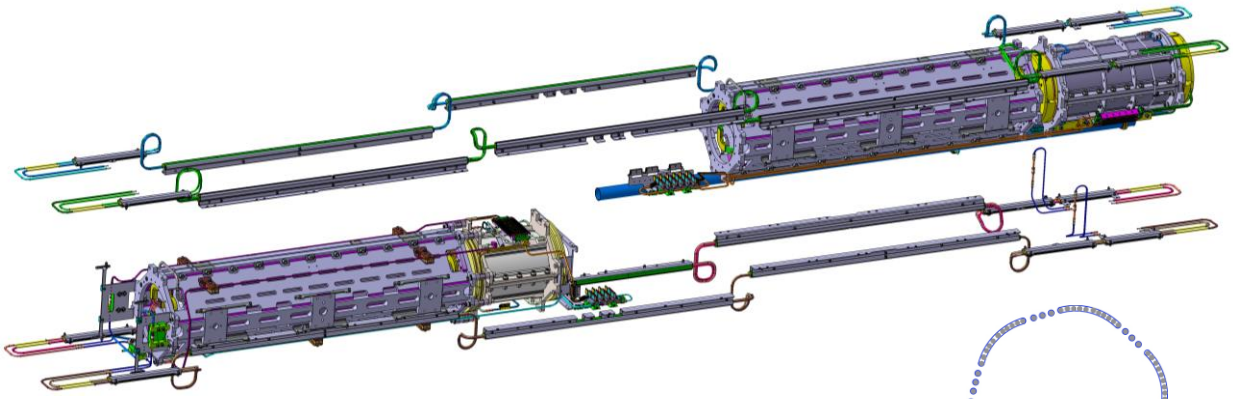


Figure 12: Quadrupole units MQDi (top) and SF1Bi (bottom)

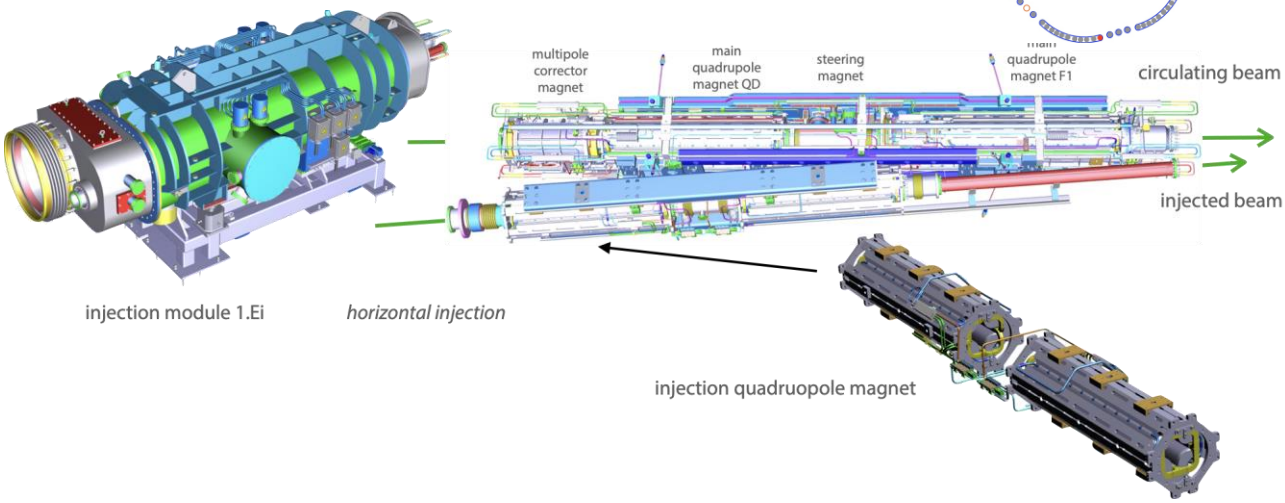


Figure 13: Low current quadrupole magnets and injection module 1.Ei

4.2.2. Superconducting magnets for Quadrupole Units

Except the gamma-t jump quadrupole magnet (a normal conducting magnet, supplied by the Company), the Contractor shall manufacture the superconducting magnets for the contracted units. The superconducting magnets are the quadrupole magnets (QD, F1, F2), the chromaticity sextupole magnet (CV, CH), the steering magnet (ST), and the multipole corrector (MC). In addition, low current quadrupole magnets for the injection and the extraction module shall be produced (QS(i) and QS(x)) and need to be contracted. Depending on the unit types as well as the location of the low current quadrupole magnets, the assembly details such as the busbars shape and routing, the location of instrumentation are individually designed. For production, the dedicated drawings shall be referred to. However, the electromagnetic design and the performance is identical for each magnet type. The detailed design and parameters are described below.

The following common design features are chosen for all superconducting magnets:

- The magnets are operated in an insulation vacuum of the cryostat and under cryogenic temperature at about 4.5 K, which is achieved by two phase helium flow in a tube in the cable as well as in tubes laid down on the iron yoke.
- The magnets are operated as fast ramped magnets. The ramp time from zero to maximum current (field) is 0.2 - 0.5 seconds depending on the magnet types.
- A hollow type cable is selected for the coil. The main quadrupole magnets are operated with a high current supplied through the busbar system along the ring. The other magnets (corrector magnets) are operated with a low current with insulated superconducting strands in the cable, and with local current leads equipped on the QDM. The interface from the current leads to the low-temperature superconductor in the corrector magnets is realized with Cold Terminals (supply from the Company), which need to be installed at the units.
- The coil is embedded in a glass fibre epoxy support structure.
- The iron yoke is made from thin laminated electromagnetic steel with filling factor above 99%.

4.2.2.1. Cross section of the magnets

Figure 14 shows the cross section of the magnets

The SIS100 main quadrupole magnet, the chromaticity sextupole magnet, and the low current quadrupole magnet are super-ferric type magnets while the steering magnet and multipole corrector magnet are cosine-theta type magnets. The yoke profiles of the main and the low current quadrupole magnets are identical (Gamma-t jump magnet as well). The yokes are half split, except the sextupole magnet having three parts, holding the coil in position mechanically.

The pole profile of the yoke of the super-ferric type magnet as well as the cable arrangement in the coil of the cosine-theta magnets are optimised and designed to generate the desired magnetic field quality fulfilling the requirements from beam optics.

The steering magnet has two independently powered coils, namely a horizontal steering coil and a vertical steering coil, which generates vertical and horizontal magnetic dipole fields. These coils are wound at the same radius of the coil support cylinder without mechanical collisions. This enables to avoid shear stress between the two coils during powering.

The multipole corrector magnet has three independently powered coils, namely a quadrupole, a skew sextupole, and an octupole coil, which are wound on a common cylindrical support structure without mechanical collisions.

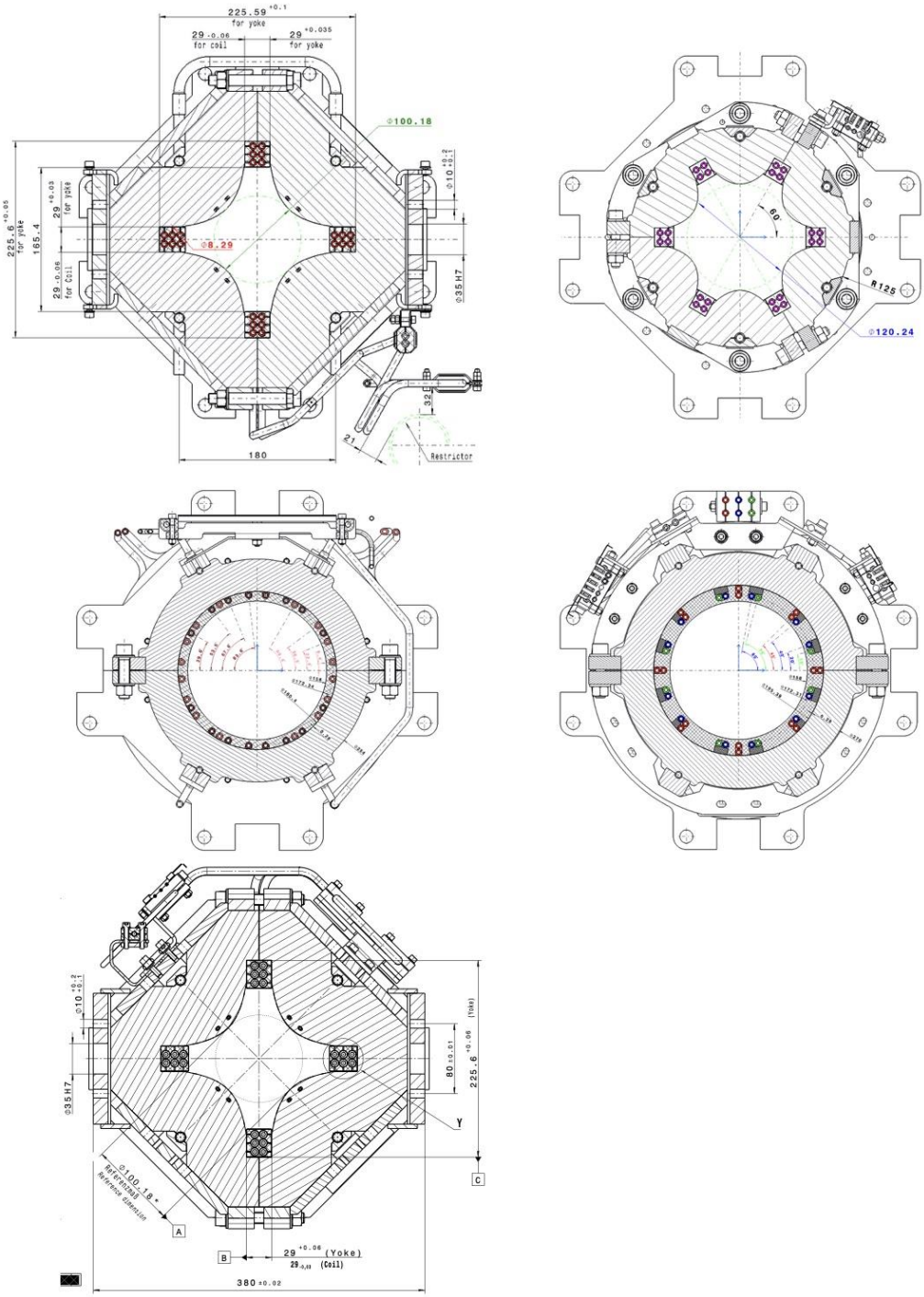


Figure 14: Magnet cross section in the magnet center: main quadrupole magnet (top left), chromaticity sextupole magnet (top right), steering magnet (middle left), multipole corrector magnet (middle right), low current quadrupole magnet (bottom left). The drawings are for information only. The dimension must be referred to with the latest drawings

4.2.2.2. Magnet overview

The main quadrupole magnet has a long busbar pair, one is coming from the coil without a joint, the other busbar is made from the SIS100 quadrupole magnet cable and attached along the coil busbar. These busbar system supplies current to the magnets connected in series in the ring. The other magnets (sextupole, steerer, multipole corrector) are equipped with a terminal box, where electrical joints of the insulated superconducting wires are made. The current is supplied by means of local current leads in the doublet setup. At the cold terminals, which need to be installed at the units by the contractor, the current is fed to a short cable section feeding the terminal boxes.

The quadrupole magnets have 6 mechanical contact surfaces along the magnet side so that the magnets can be precisely mounted and aligned on a girder system for the QDM installation. The sextuple, the steering, and the multipole corrector magnets are mechanically aligned to the main quadrupole magnets by means of precisely machined connection flanges.

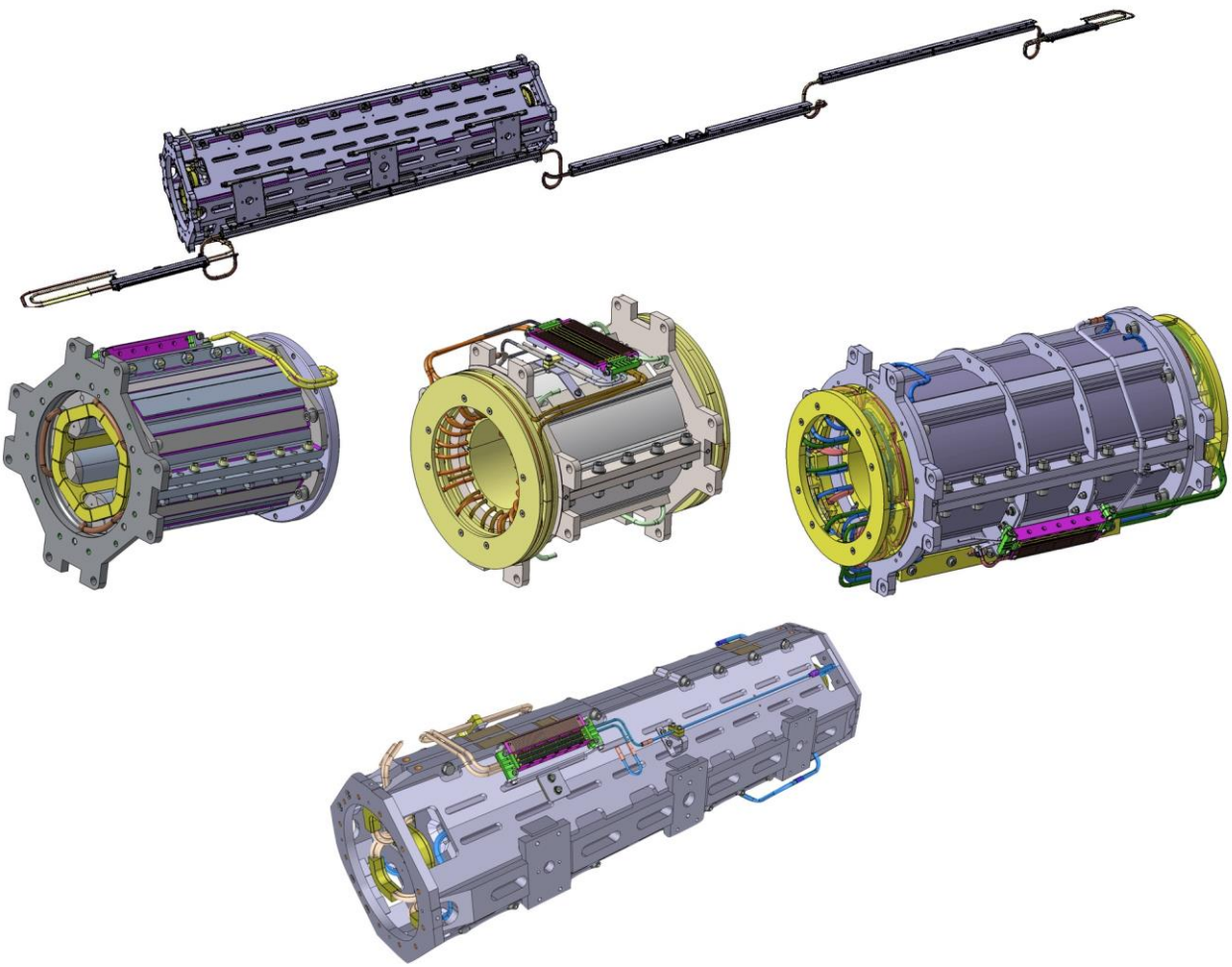


Figure 15: Overview of the magnets: main quadrupole magnet (F2, top), chromaticity sextupole magnet (middle left), steering magnet (middle center), multipole corrector magnet (middle right), low current quadrupole magnet (bottom). Information only, picture size is not proportional to the dimensions.

4.2.2.3. Superconducting coils

Figure 16 shows the coils of the magnets. Though the shape of the coils is different, common technologies are adapted for the production.

The coil shall be made from one continuous cable without joints. The coil has to be wound on precisely machined frame or coil support structure parts (made from G11) without damages on the cable. The extremity of the cable has to be carefully protected before starting of the winding. The winding has to be done without any contamination of dusts, metallic fragments, or liquid. Multiple bending and unfolding of the cable, which possibly damages the cable, shall be avoided. The radius of the cable bending must be larger than the specified minimum bending radius. The bending must be formed with appropriate tools.

The positions of the cable (centre of the cable) in the magnet cross section and the longitudinal length of the coil are essential to determine the magnetic performance of the magnet such as field quality and integral magnetic field strength. Therefore, the deviation shall be kept in the tolerances specified in the drawings.

The wound coil is embedded in a G11 support structure. The direction of glass fibres in the parts affects the thermal contraction behaviour. Therefore, the manufacturer has to follow the instruction indicated in the drawings. The grooves of the support structure for placing of the cable have to adapted to the manufactured cable diameter. The required diameter of the groove may be determined by a mock-up with a short cable sample and G11 parts. The position of the cable centre shall be kept. The G11 parts, in particular those at the bending part of the coil, and the shape of the grooves shall be optimized to fulfil the specified tolerances.

The G11 parts have to be mounted on the coil without any damages on the cable. Sharp edges and burr, which cause insulation damages on the cable, shall be removed. The contact surface of the G11 part to the cable has to be coated by the epoxy glue, which is polymerized during a heat treatment process.

The coil embedded in the G11 support structure is put in the mould and a heat treatment process is executed. During the heat treatment, the temperature shall be carefully controlled to minimize the temperature differences across the coil. All the epoxy has to be polymerized by the heat treatment. Un-polymerized, liquid form epoxy, which may cause degradation of the dielectric strength, shall be avoided. The dimension of the coil after the heat treatment is defined by the dimension of the mould. Therefore, the mould has to be designed and manufactured precisely according to the final dimension of the coil. Any changes or re-machining of the mould during the series production, which cause the variation of the coil dimension, shall be avoided.

After the heat treatment, the coil has to be carefully released from the mould when the coil has reached room temperature. The dimensions of the coil have to be measured at room temperature conditions. Visual checks have to be executed as well.

The coil has to be bandaged by prepreg tapes after the first heat treatment. Space for the voltage taps should be carefully prepared and kept free. The coil has to have a second heat treatment. After the second heat treatment, the coil has to be carefully released from the mould when the coil has reached room temperature. At this moment, the dimensions of the coil have to be measured. Visual checks have to be done as well. Both dimension and visual inspection results must be submitted to the Company in written form as a report.

After these processes, the coil shall be covered by e.g. a plastic sheet to protect the coil from contamination, pollution, and mechanical damage. The coil shall be stored under appropriate temperature and humidity conditions.

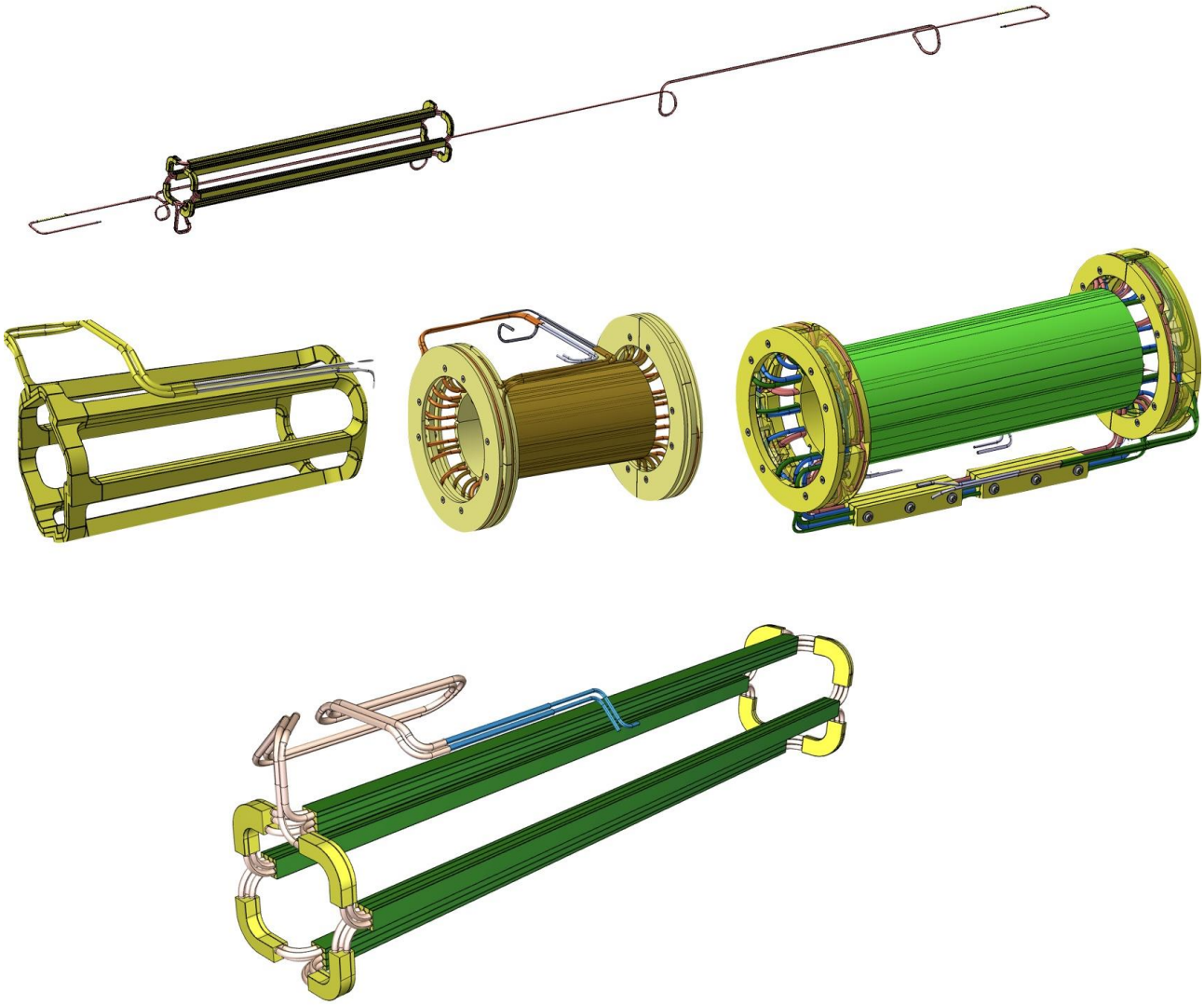


Figure 16: Coils of the magnets: main quadrupole magnet (F1, top), chromaticity sextupole magnet (middle left), steering magnet (middle center), multipole corrector magnet (middle right), low current quadrupole magnet (bottom). The figure is for information only; the individual pictures do not use the same scaling factor.

4.2.2.4. Superconducting cables

There are 3 different superconducting cables required for the SIS100 superconducting magnets, namely for the main quadrupole, for the corrector magnets (the steering magnet, the chromaticity sextuple magnet, and multipole corrector magnet), and for the low current quadrupole magnet.

Basically the superconducting cable consists of a cooling tube, superconducting strands, a fixation wire, and insulation tapes. The strands are twisted around a cooling tube and fixed by turns of the fixation wire. Then, electrical insulation covers the cable. Figure 17 shows an overview of the cables. To adjust the spacing of the strands and assure the mechanical stability, one or two synthetic wires can be added in the layer of the strands.

There are two cable technologies, namely a dry cable and a wet cable. A dry cable is wrapped with polyimide tape as the insulation, while a wet cable has wet epoxy resin in a glass fibre insulation and around the superconducting wires. A wet cable shall be formed to a coil before degradation of the epoxy property. The heat treatment of the coil polymerises the wet epoxy of the cable. Since the glass fibre tape with epoxy resin is thicker than polyimide tape, the outer diameter of a wet cable would be slightly larger than that of a dry cable.

The Contractor shall investigate the cable technologies and finalise the cable designs fulfilling all requirements for the magnets. An optimum set of production characteristics has to be developed and agreed with the Company (e.g. tension of strands and wires). Special care has to be taken with respect to the integrity of the insulation after cable production and coil winding, especially for the corrector strands. The coil design (diameter of the grooves in the support structures etc.) shall be adapted to the final cable design and realization. Table 5 shows design parameters of the cables.

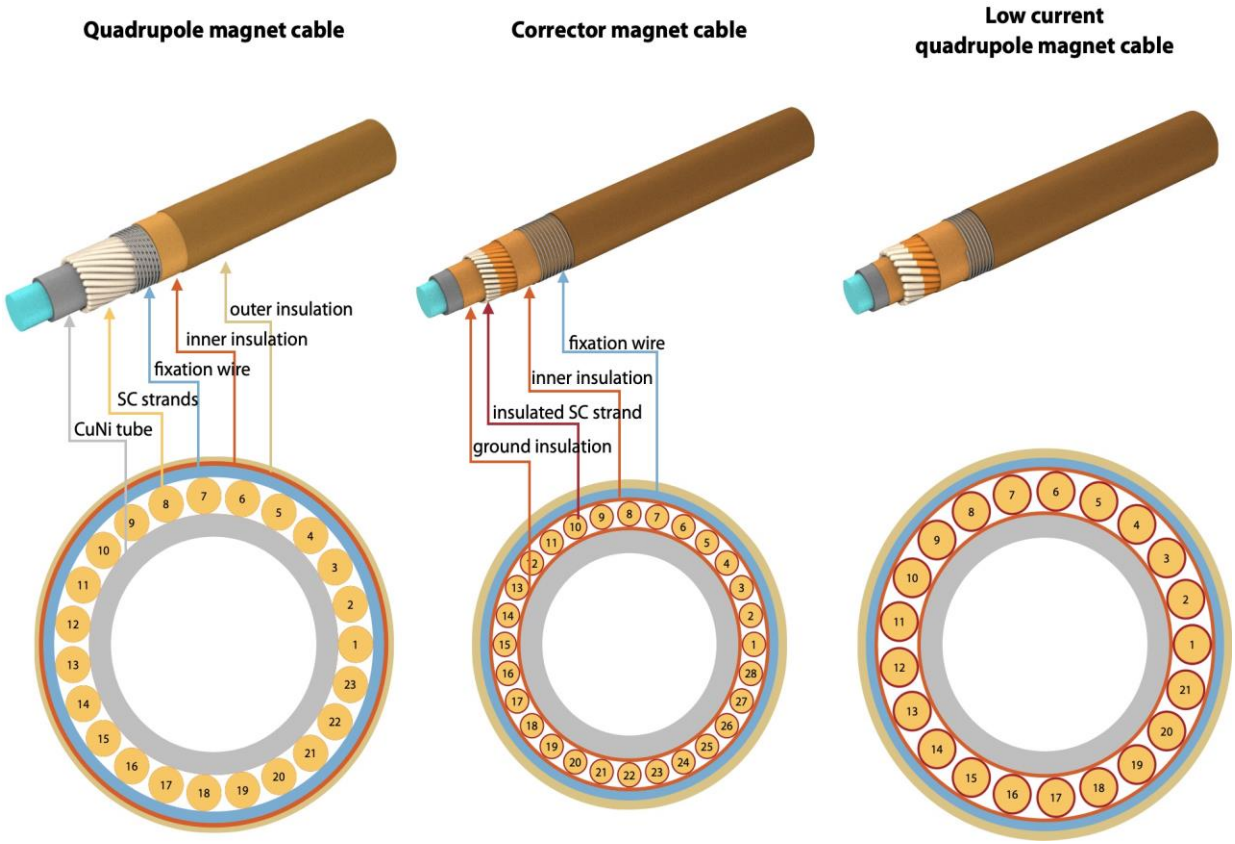


Figure 17: Schematic view of the superconducting cables. Low current quadrupole magnet cable has same composition as the corrector magnet cable. Note that the twist direction of the corrector magnet cable needs to be realized as left handed instead of right handed as shown here.

Table 5: Cable design parameters

	Composition		Quadrupole magnet cable	Corrector magnet cable	Low current quadrupole magnet cable
1	Cooling tube	material	CuNi	CuNi	CuNi
		inner diameter (mm)	4.71	4	4.71
		outer diameter (mm)	5.71	5	5.71
2	Ground insulation for tube	material	-	Polyimide tape	Polyimide tape
		thickness (mm)	-	0.08	0.08
		overlap	-	50% of 0.04 thick tape	50% of 0.04 thick tape
3	Superconducting strand	bare strand diameter (mm)	0.8	0.5	0.8
		insulation thickness (mm)	-	0.05	0.05
		number of strands	23	28	21
		Transposition pitch (mm)	50	50	50
4	Fixation wire	material	NiCr 8020/ 2.4869	Synthetic	Synthetic
		diameter (mm)	0.25	0.2	0.2
		Transposition pitch (mm)	0.6	0.6	0.6
5	Outer insulation (inside)	material	Polyimide tape	Polyimide tape	Polyimide tape
		thickness (mm)	0.08	0.08	0.08
6	Outer insulation (outside)	material	Polyimide tape	Polyimide tape	Polyimide tape
		thickness (mm)	0.14	0.14	0.14
	(wet cable option)	material	Glass fiber tape	Glass fiber tape	Glass fiber tape
		thickness (mm)	0.22	0.22	0.22
	Cable diameter	dry (mm)	8.25	7.2	8.51
		wet (mm)	8.41	7.36	8.67

The superconducting strands for the corrector magnet cable and the low current quadrupole magnet cable are individually insulated so that the magnets can be operated by a current flow in the individual strands connected in series. In addition, one of the strands will be used for pick-up of a quench signal for a mutual inductance detector (MID). Therefore, it requires ground insulation around the cooling tube as well as an additional insulation layer around the superconducting strands before introducing the fixation wire to avoid damage on the strand insulation. The twist direction of the strands in the cables shall be left-handed as shown in Figure 18 due to the design of the terminal box.



Figure 18: Direction of the strand twist in the cable. Only left-handed twist is allowed due to terminal box design constraint.

For the cabling process, the materials have to be arranged on the cabling machine without any damages. The manufacturer shall avoid any contamination (metallic fragment, dust, liquid) in the cable, which may cause damages of the strand and insulation. Cleanness of the working place is essential.

4.2.2.5. Yoke

The yokes for the magnets are made from a stack of electromagnetic steel lamellas. The Company supplies the necessary amount of steel sheet material (M600-100A, with electric insulation coating) to the Contractor. The lamella shall be formed by stamping or by laser cut.

The thickness of a steel sheet material varies from the centre to the edges. Furthermore, the magnetic properties may vary with respect to the rolling direction (even for material specified as isotropic). The accumulation of the thickness and the magnetic property differences in the stack of yoke shall be avoided by suitable combination of the lamellas. For this, the Company might ask for a dedicated sorting routine based on measurement results on the lamellas.

The stack of lamellas shall fulfil a minimum filling factor (99%) by adjusting the number of lamellas in the length of the yoke. The stack shall be fixed by the end plates and the side bars by welding. Heating of lamellas by welding, which may change the magnetic properties, shall be avoided. In case a welding process is required, it shall be agreed with the Company. After the assembly, the dimension and weight of the yoke package have to be measured and reported. The final pole profile manufacturing may be completed by milling process. Then, the yoke package should be covered by plastic sheet to protect from contamination, pollution, and mechanical damage and then stored under appropriate temperature, humidity conditions.

The geometry of the yoke is essential for the magnetic performance of the magnet. The contractor shall introduce a geometrical measurement routine, which needs to be agreed with the Company. It needs to confirm that the geometry is fulfilling the specified precision.

The yoke should be protected from corrosion in a vacuum compatible way at all times.

4.2.2.6. Superconducting magnet parameters

Table 6 shows characteristics and operation parameters of the four types of superconducting magnets in the units.

Table 6: Parameters of the superconducting magnets

name	Quadrupole magnet	Chromaticity sextupole magnet	Steering dipole magnet (Horizontal / Vertical)	Multipole corrector magnet (quadrupole, sextupole, octupole coil)	Low current quadrupole magnet
n (2n-pole field), normal or skew	2, normal	3, normal	1, normal / 1, skew	2, normal / 3, skew / 4, normal	2, normal
Magnet type	Super-ferric	Super-ferric	Cosine-theta	Cosine-theta	Super-ferric
Number of turns per pole	3	2	4 / 4	1 / 1 / 1	3
Powering	Unipolar	Bipolar	Bipolar	Bipolar	Unipolar
Magnetic property					
Maximum nominal integral field gradient [T/m^(n-1)*m]	35.1	175	0.3	0.5625 18.75 250.00	27.5

Maximum nominal field gradient at magnet centre [T/m^(n-1)]	27.77	232	H:0.372 V:0.366	0.75 25 333.33	25.51
Magnetic length at maximum nominal field gradient [m]	1.264	0.383	H:0.403 V:0.410	0.62 0.59 0.56	1.078
Magnetic field quality at 40 mm radius	$<\pm 6\times10^{-4}$	$<\pm 10\times10^{-4}$	$<\pm 6\times10^{-3}$	$<\pm 6\times10^{-3}$	$<\pm 6\times10^{-4}$
Electric property					
Inductance [mH]	0.38	44	H:27 V:27	1.15 5.59 7.43	123
Current at maximum nominal field gradient [A]	10512	252	H:236 V:232	236 248 250	511
Ramp time from 0 to the maximum nominal current [sec]	0.463	0.175	0.2	0.2	0.5
Maximum voltage across the magnet coil In accelerator operation cycle [V]	8.6	57	33.7	1.8 5.8 7.7 (to be measured)	104 (to be measured)
Maximum voltage across the magnet coil In case of quench [V]	43	323	375	383 383 383	865
Maximum voltage to ground In accelerator operation cycle [V]	356	171	17	0.9 2.9 3.9 (to be measured)	52 (to be measured)
Maximum voltage to ground In case of quench [V]	894	485	187	191 191 191	433
Maximum stored energy [kJ]	26	1.76	1.04	0.046 0.212 0.280	21.2
Dimensions (rough numbers. precise values must be found in the drawings)					
Pole tip radius for superferric type, yoke inner radius for cosine theta magnet [mm]	50	60	67.5	67.5	50
Yoke length [mm]	1203	351	300	640	1000
Cable length for coil [m]	46	15	15	12 14 17	45
Magnet overall length [m]	1.4	0.44	0.43	0.7	1.1
Magnet overall height [m]	0.41	0.41	0.41	0.35	0.41
Magnet overall width [m]	0.39	0.41	0.41	0.35	386
Magnet weight [kg]	850	145	120	175	640

4.2.3. Busbar

A detailed specification for busbars and voltage taps in the SIS100 quadrupole modules is available (https://edms.cern.ch/document/1447831). The units shall be produced in accordance with the specification. Uninsulated parts shall be kept as short as possible.

Helium flow and process pipe

The following specifications are particularly relevant for process piping for the helium flow:

- F-CS-MT-04e Common specification of the cooling system of the superconducting SIS 100 magnets (https://edms.cern.ch/document/1274168)
- F-DS-MT-71e Detailed Specification of the Cooling System of the Regular Arc Quadrupole Modules for SIS100 (https://edms.cern.ch/document/1275675)
- F-DS-MT-79e Detailed Specification of the Cooling System of the Quadrupole Modules in the Straight Sections of SIS100 (https://edms.cern.ch/document/1346794)
- F-DS-MT-83e Detailed Specification of the Cooling System of the Arc Termination Quadrupole Modules for SIS100 (https://edms.cern.ch/document/1532603)

The units shall be produced in accordance with the specifications listed above and AD 2000 Category 1. All piping has to be clean and dust free. Proper precautions shall be taken by contractor to keep this state throughout production and transport.

For SAT testing, the interfaces of a test cryostat might differ from the conditions in the doublet assembly. Temporal conditions of, e.g. for an overlength of the helium piping need to be mutually agreed at the FDR of the units.

4.2.4. Instrumentation

The instrumentation shall be produced according to the detailed specification of instrumentation for the SIS100 Quadrupole-Modules (https://edms.cern.ch/document/1561225).

4.2.5. Soldering, Brazing, and Welding

All solder shall be RoHS compatible. If a document specifies otherwise, the contractor shall seek for clarification with the company.

All welds have to be executed and documented in accordance with the Technical Guideline for Welding Practices (https://edms.cern.ch/document/2383347). Additionally, welds on tubing with an outer diameter smaller or equal to 6 mm shall not degrade the inner diameter of the tube. For visual tests (VT) test records shall be made in accordance with DIN EN 17637 on seam level and document quantitatively all deviations from the ideal weld and its classification.

All brazing has to be performed according to AD 2000, in addition an audit of procedures according to DIN EN 13134 has to be performed by the contractor and corresponding documentation provided. The brazing solder needs to be certified according to ISO 3677 or DIN EN 1044; corresponding proof has to be provided by the contractor. The contractor has to provide a test certificate at least according to DIN EN ISO 10204:2004 2.2 for the brazing solder. Brazing has to be performed by certified brazing personnel or certified operators only. The certification has to be done according to DIN EN

13585, corresponding certificates have to be provided by the contractor. The inspection of the brazing has to be done in accordance with AD 2000 on the production seam. The inspection and its result has to be properly documented for each inspected brazing individually.

4.3. **Tolerances**

The general information of tolerances on the units are mentioned in this section. The Contractor shall follow mechanical tolerances specified in the approved drawings as well as the description in this section. Any reference to ISO 2768-2 shall be interpreted as reference to ISO 2768-2:1991; ISO 22081 is not valid in context of this project.

4.3.1. Unit

The main quadrupole magnet is the core component of the units. The main quadrupole magnet has mechanical reference surfaces to be used for mounting and precise alignment of the units on a common girder in the doublet module setup (see Figure 19). The contractor shall follow the mechanical tolerances specified in the related drawings.

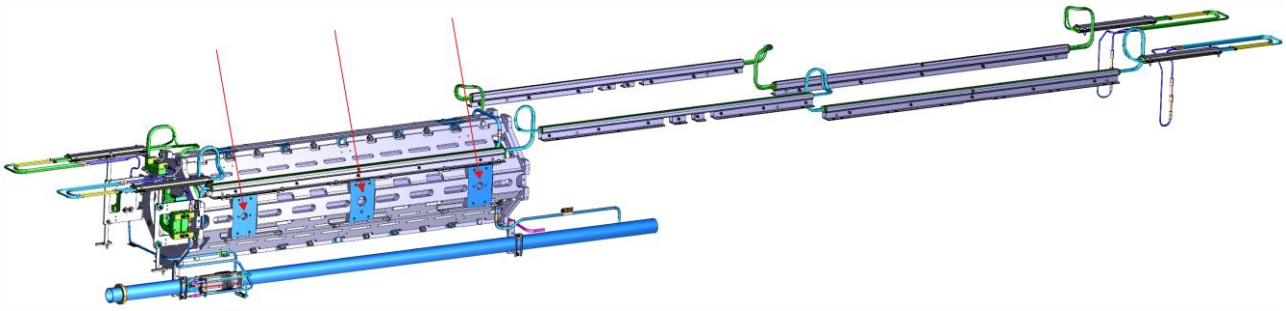


Figure 19: Reference surfaces on the quadrupole yokes used for unit alignment in the doublet setup indicated by the arrows.

Within the units' assembly, the other components, namely the corrector magnets, busbars, helium process pipes are precisely mounted with respect to the main quadrupole magnet as specified in the drawings (see also Sect. 4.3.2.3).

For positioning checking purpose, mechanical templates may be used in the assembly process.

4.3.2. Magnets

The magnetic field and its quality in the magnet aperture is created and defined by the geometry of the coil and the iron yoke as function of the electrical current in the coil. The tolerances of magnet parts, especially the lamella and coil as well as the tolerances of magnet assembly have significant impact on the magnetic field quality. In this section, the tolerances of the yoke, coil and the magnet assembly are given. The Contractor shall follow the given tolerances in the drawings. The Contractor must prove that the specified tolerances are kept during the production process. In the FDR, the Contractor shall present a plan how to prove and report it.

With an example of the quadrupole magnet, the general conditions of mechanical tolerances of the magnet yokes are described. The concept and the tolerance shall be applied for all magnet types.

Important for the magnetic field quality are the pole profile, the position of the centre of the cable in the coil, and the position of the saturation holes with respect to the beam axis (nominal centre of the magnet).

4.3.2.1. Assembled magnet: Yoke and coil in the cross section

In any local cross section of the assembled magnet, except the magnet ends, the tolerances specified in Figure 20 shall be kept. The tolerance in the pole profile in the aperture is required to be ±50 µm. The center of the cable in the coil cross section needs to be positioned with a precision of ±100 µm. The saturation holes need to be positioned with ±500 µm precision.

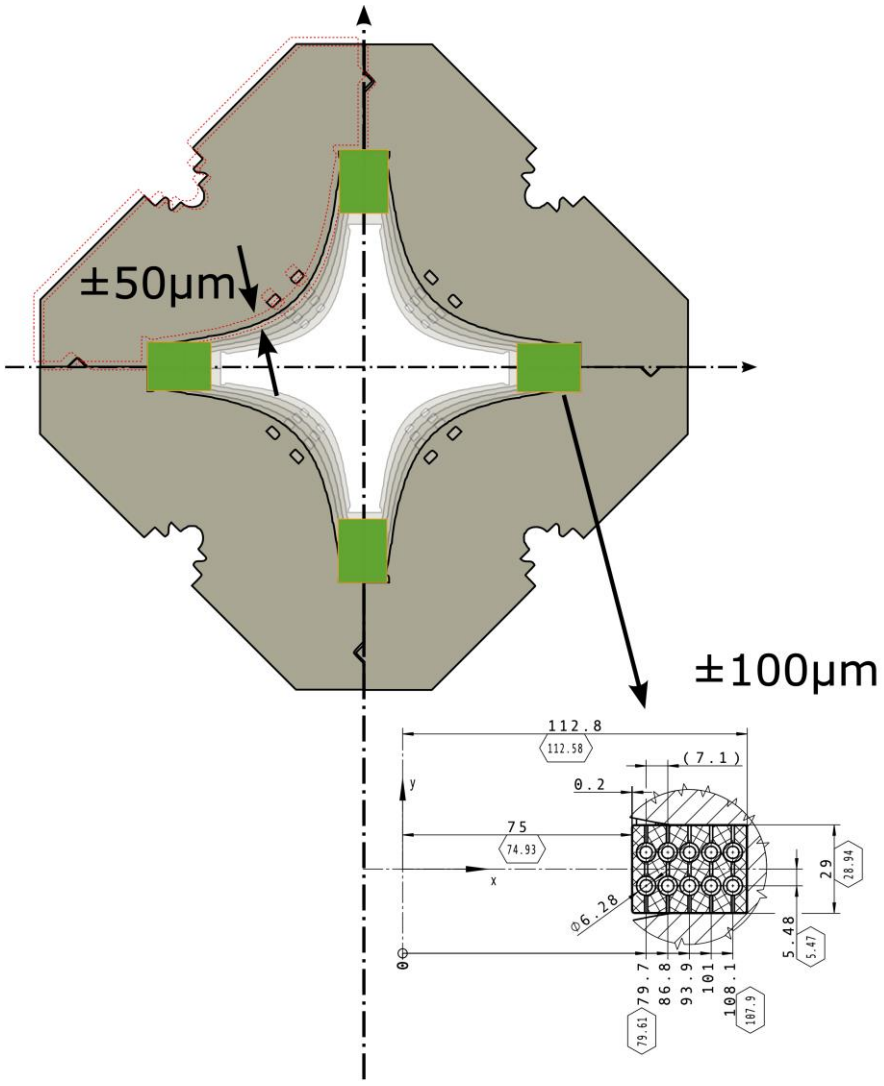


Figure 20: Schematic view of the tolerance of the assembled magnet in the cross section. Yoke: The tolerance is ±50 µm with respect to the specified aperture profile. Coil cable: The tolerances of the center of the cable in the coil package with respect to the yoke are specified to ±100 µm. The saturation holes need to be positioned with precision of ±500 µm.

4.3.2.2. Assembled magnet: Each cross section along beam direction axis

The variation of the inner pole profile in the cross section along the beam (longitudinal) direction shall be below ±100 µm as shown in Figure 21. This includes deformations like sag or twist of the yoke. This tolerance is valid only for the inner profile in the yoke.

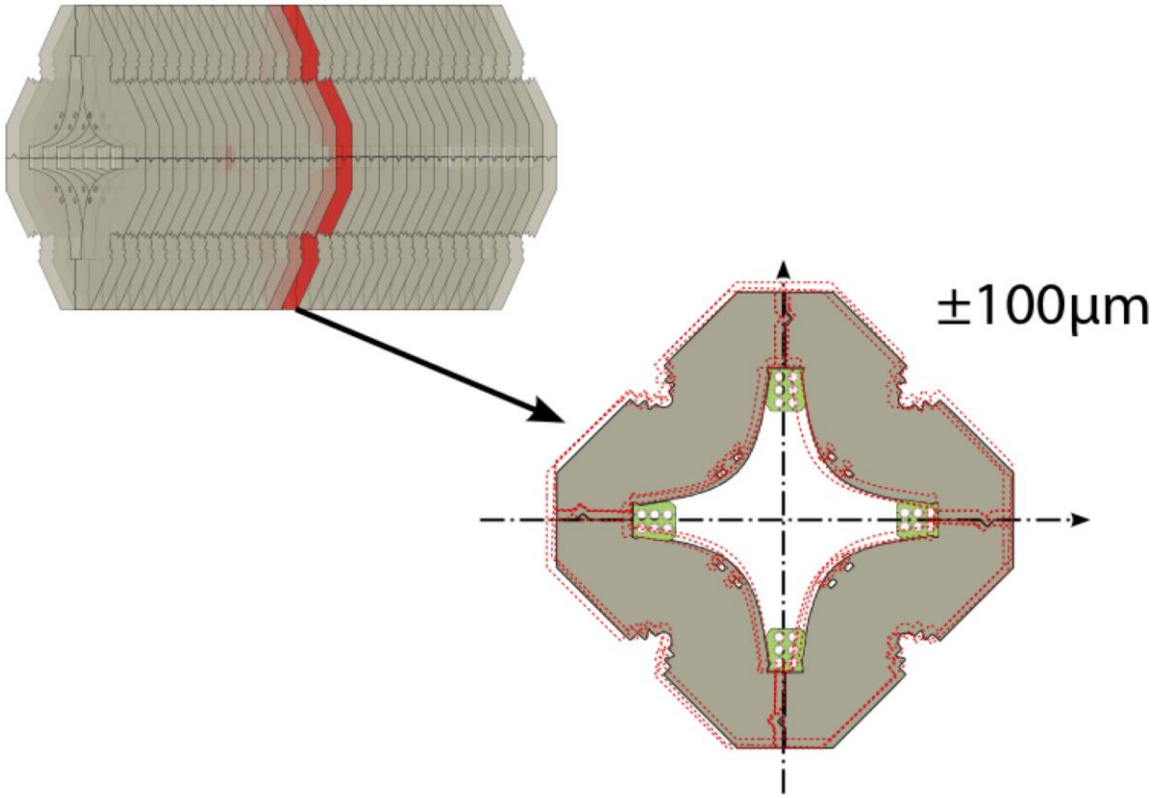


Figure 21: Schematic view of the tolerance of the assembled magnet over the length. The tolerance with respect to the specified profile (by x-, y-shift, rotation) is ±100 µm.

4.3.2.3. Assembled unit: alignment of the corrector magnet to the quadrupole magnet

The holes on the flanges of the quadrupole magnet are used to define the coordinate system of the units and are used to confirm the aligned position of the quadrupoles in the doublet setup. The specified tolerances from the corresponding drawings have to be followed.

The other magnets attached to the quadrupole magnet have no own mechanical reference nor adjustment system after the unit assembly. Therefore, a high precision at the alignment of the corrector magnets to the quadrupole magnet, which is done by precise mechanical connection (see Figure 22), is essential to maintain the magnetic performance of these magnets.

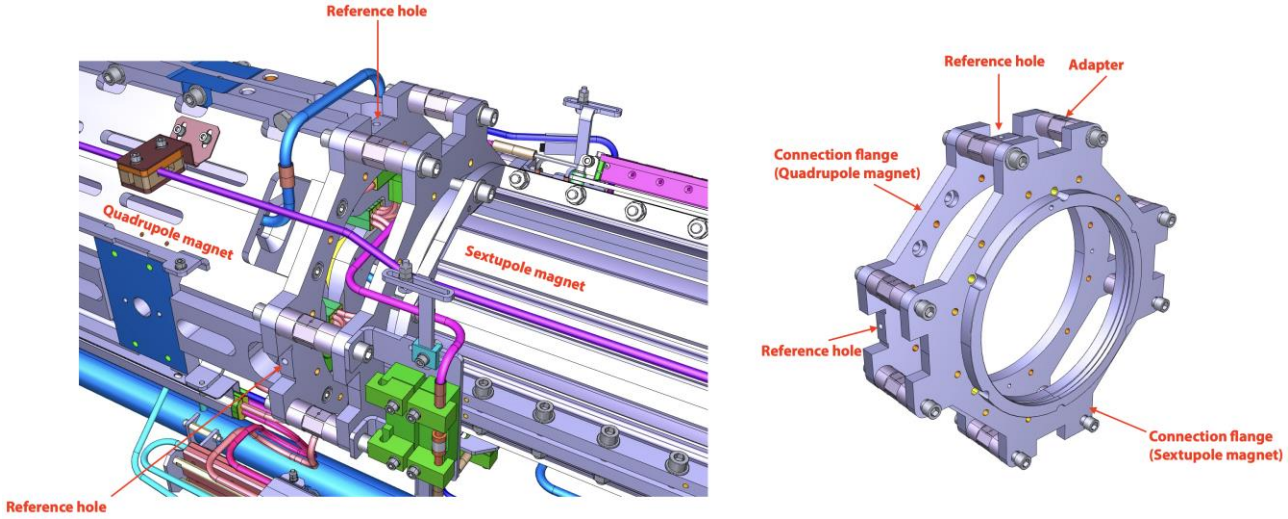


Figure 22: Example of the connection of the corrector magnet to the quadrupole magnet (the sextupole magnet and the quadrupole magnet). The center of the connection flange is precisely aligned to the center of the yoke aperture. The mechanical connection is realized with 8 adapter pieces. Machining precision of the parts and assembly tolerances must be followed by the drawings.

4.4. Interfaces

The units have several interfaces to neighbouring devices, components, and items. In this section the interfaces are described.

4.4.1. Electric interface

Electric power is supplied to the magnets. For the main quadrupole magnets as well as the main dipole magnets, the excitation current will be supplied through the cryogenic busbar system along the SIS100 ring. The units contain the busbars with electrical contact parts to neighbouring modules (QDM, dipole magnet modules, missing dipole module, bypass line).

For the corrector magnet, the electric current is supplied via a cold terminal of the units. The cold terminal has electric contact to the local current leads on the quadrupole doublet module cryostat.

Voltage taps are mounted on the circuit of both main quadrupole magnets, corrector magnets, and the busbars. The voltage taps are connected to sockets on the quadrupole doublet module cryostat.

Details of the interface are described in the relevant reference documents.

- F-DS-MT-80e Bus-Bars and Voltage Taps in the SIS100 Quadrupole Modules, https://edms.cern.ch/document/1447831
- F-DS-MT-108e Instrumentation for SIS100 Quadrupole Modules, https://edms.cern.ch/document/1561225

4.4.2. Hydraulic interface

By means of cryogenic helium flow the units are cooled. Gaseous and liquid Helium is supplied from and returned to process pipes.

Details of the interface are described in the relevant reference documents.

- F-CS-MT-04e Common specification of the cooling system of the superconducting SIS 100 magnets (https://edms.cern.ch/document/1274168)
- F-DS-MT-71e Cooling system of the regular arc quadrupole modules for SIS100, https://edms.cern.ch/document/1275675
- F-DS-MT-83e Cooling System of the Arc Termination Quadrupole Modules for SIS100, https://edms.cern.ch/document/1532603
- F-DS-MT-79e Cooling System of the Quadrupole Modules in the Straight Sections of SIS100, https://edms.cern.ch/document/1346794

4.4.3. Vacuum interface

The unit is mounted in a quadrupole doublet module cryostat, which provides insulation vacuum. The unit does not have direct contact to atmosphere but will be operated under vacuum condition.

Details of condition units in vacuum are described in the relevant reference documents.

- F-DS-MT-107e Specifications of quadrupole doublet module, https://edms.cern.ch/document/1533009

4.4.4. Instrumentation interface

The temperature sensors and heaters for the restrictor are mounted on the units. In the corrector magnets, one of the superconducting strands of the cable is used for quench signal pick-up. The wire from the sensors, heaters, and quench detection strands are guided and finally connected to the sockets on the cryostat instrumentation flange.

Details of the instrumentation and interfaces are described in the relevant reference documents.

- F-DS-MT-80e Bus-Bars and Voltage Taps in the SIS100 Quadrupole Modules, https://edms.cern.ch/document/1447831
- F-DS-MT-108e Instrumentation for SIS100 Quadrupole Modules, https://edms.cern.ch/document/1561225
- F-DS-MT-107e Specifications of quadrupole doublet module, https://edms.cern.ch/document/1533009

4.4.5. Mechanical interface

Mechanical interfaces are required in addition to the physical connection of electrical, hydraulic, and instrumentation interfaces. The main quadrupole magnet has six contact surfaces to the common girder used to align two units accordingly (see Figure 19). Here, the mechanical precision of manufacturing is of importance for later precise alignment of two units to each other (in the doublet setup).

A vacuum chamber will be installed into the aperture of the unit in the doublet integration process. The mechanical fixation and holding system for the vacuum chamber is introduced then.

Some of the units are connected to a beam position monitor, a cryo-collimator or a drift tube with a cold-warm transition for a vacuum pump. High contact precision must be assured as specified in the drawings.

4.4.6. Alignment interface

The position and direction of the main quadrupole magnet in the integrated doublet setup determines the position and direction of the unit. Precisely manufactured reference holes on the main quadrupole magnet are used to define a coordinate system, and are used for the alignment of the units and verification of the positioning. The magnetic properties like the quadrupole magnetic axis position is measured and correlated to the coordinate system defined with the reference holes. Thus, the

reference holes themselves need to be placed with high precision as defined in the corresponding drawings.

5. Procedure of the project

5.1. Kick-off meeting

A kick-off meeting with representatives from the Contractor and the Company shall be organized to start the project. The kick-off meeting is aiming to reach common understanding on:

- a way of communication between both parties
- project organization, members, and scopes
- unit specification (including naming conventions defined by the Company)
- quality assurance
- project duration

The Contractor shall present:

- detailed schedule
- project plan (resource deployment, factory space and setup, tooling and material procurements, storage space, shipment and transport strategy)
- project oriented risk analysis on above project plan for the whole project period

From the kick-off meeting, a detailed project schedule shall be agreed including all project milestones. The project organization, resource plan, production capacity, procurement plan must be implemented to the schedule.

In addition, the regular project communication (including steering meetings) shall be established. The Contractor shall provide progress and status reports and update the schedule regularly (e.g. weekly status meeting and monthly report submission).

Since there are several unit types for the quadrupole doublet modules, the Contractor can propose stepwise (unit-pair-type by unit-pair-type) FDRs and production runs. The Company and the Contractor shall mutually agree upon a sequence of the units for the modules.

5.2. Final design phase

Based on the provided information (specifications, drawings, 3D models, and technical guidelines etc.), the Contractor shall make:

- a quality inspection and production plan (QIPP)
- work instructions
- a list of the materials of the units
- a schedule of the production
- a set of the drawings of the units
- a set of the tooling for the production
- a functional verification of the design provided by the Company
- a verification of compliance of the design with the relevant standards and norms (e.g. Pressure Equipment Directive, AD 2000 at least Category 1).

The QIPP describes and defines each step of the unit production (from material incoming inspection to the assembled unit shipment) and the testing and inspection steps as well as holding points, notification points, and written reports.

If the Contractor proposes a change from the provided design by the Company, an Engineering Change Request (ECR) document describing the detail of the changes and the impact shall be prepared and submitted to the Company. The change is allowed only after official approval by the Company.

5.2.1. **Final Design Review (FDR)**

The contractor shall submit all the drawings, 3D models, QIPPs, work instructions and further documents for the production at least two weeks before the Final Design Review. In the Final Design Review meeting, the contractor shall explain the procedure of the manufacturing from the material procurements to the completion of the unit assembly. Especially, changed points from the Company design shall be stressed by the Contractor to make an agreement with the Company with an ECR. The list of the materials is presented with a list of the relevant material certificates necessary for the FAT approval process. A schedule of the production shall be presented.

The FDR approval shall be done by the Company. Only after approval by the Company, the Contractor can start the production.

5.3. **Production phase**

5.3.1. **From FDR to the unit production**

The Contractor shall procure materials for production of the units and the tooling. The Contractor shall collect the EU standards and directive relevant certificates of the materials for each part of the magnet. The Contractor shall produce the units in accordance with the company approved drawings and QIPPs. A set of documents (as-built drawings, as-built 3D model, filled QIPPs, certificates of materials, welding & brazing certification, test reports, etc.) shall be submitted to the Company.

5.3.2. **FAT, shipment, SAT, and acceptance of the units**

The produced units shall be subjected to a Factory Acceptance Test (FAT) at room temperature condition where the scope of the testing program is defined in Sect. 6.2 and in Annex 01 of F-DS-SCM-en-MT_0152. The FAT is conducted by the Contractor. The complete set of reports and protocols from the FAT shall be prepared by the Contractor and submitted to the Company for review and decision of acceptance. The Contractor shall submit the Company-requested data (electronically readable format, Excel file or CSV format). On request of the Company, a FAT review meeting shall be arranged.

After successful FAT approval by the Company and with an explicit permission of the Company, the units shall be transported to GSI, Darmstadt (or possibly GSI specified place) for the Site Acceptance Test (SAT). The SAT both at room and cryogenic temperature is conducted by the Company. The Company prepares SAT reports and protocols and makes an acceptance decision. The Company

communicates the decision to the Contractor. Accepted units are supplied to the QDM integration steps, which are not scope of this specification.

If there is a change from the initial unit design, the Contractor shall prepare an engineering change request (ECR) and submit it to the Company for approval. After approval of the ECR by the Company, the production can be resumed with the approved change.

5.3.3. **Completion of the project**

After acceptance of all deliverables (SAT acceptance and delivery of the last deliverable), the tooling shall be stored properly for an agreed period at the Contractor or delivered to GSI, Darmstadt with the permission of the Company. The project ends by acceptance of all deliverables and the tooling delivery, and the approval of all documentation.

6. Quality Assurance, Tests and Acceptance

In this section, topics related to the quality assurance are defined.

6.1. Quality assurance measures

6.1.1. Quality inspection and production plan (QIPP)

The Contractor shall prepare Quality Inspection and Production Plan (QIPPs). The plan shall be reviewed and approved by the Company before starting of the production at the corresponding FDR. The unit can be rejected if the Quality Inspection and Production Plan is not prepared or not properly used and filled during the production. The filled QIPP shall be submitted to the Company for FAT approval.

6.1.2. Incoming goods inspection

The contractor shall apply an incoming goods inspection for all components and assemblies. The contractor shall be responsible for planning and application of any further incoming goods inspection. In case, further information on testing parameter for more detailed incoming goods inspection is needed, the Contractor may request such information at the Company in writing. All applied incoming goods inspection must be documented in detail. The planning of incoming goods inspection shall be introduced to the Company at least 8 weeks prior to start of production.

6.1.2.1. General test procedures

The following checks must be performed in general for all deliveries:

- transportation packaging shall be checked for visible damages and contamination,
- transportation-data-logger or any tilt-, humidity-, shock-indicators must be read out and analysed,
- number of delivered components must be checked for completeness,
- documentation as specified for any supply shall be checked for completeness and correctness,
- packaging shall be checked for integrity,
- packaging shall be checked for cleanliness,
- Visual check for overall integrity and undamaged functional elements,
- CID-code of components shall be checked for correct assignment to serial-number (or equivalent).

In case of damaged or contaminated packaging or conspicuously high read-out of transportation-data (shock, tilt, humidity etc.) is registered, a very detailed inspection of affected components must be performed.

In case of any non-conformity is recognised during incoming goods inspection, the Contractor shall prepare according documentation and shall inform the Company.

6.1.3. **Factory access**

The Company and its representatives shall have free access during normal working hours to the manufacturing or assembly sites, including any subcontractor's premises, during the project period.

6.1.4. **Regular reporting and meeting**

The Contractor shall submit a report which describes the status and prospective plan of the material preparation and production of the units. Regular meetings (both technical meeting and project steering meeting) shall be arranged. The frequency of them has to be agreed with the Company and the Contractor.

6.1.5. **Non-conformity report**

Failures and deviations in the production process have to be reported as a non-conformity report (NCR) immediately. For example, the following topics are categorized as non-conformity:

- Deviation from the specification (unit functionality etc.)
- Deviation from the drawings (dimensions, tolerances, materials, etc.)
- Missing of the documentation (certificate, data file, test protocol, etc.)
- Skip of a measurement, a test, or an inspection
- Uncontrolled working environment (dust, water, humidity, etc.)
- Changes without engineering change request or without approval by the Company, etc.

The NCR shall describe: Details of the non-conformity, impact of it, a proposal for repair/mitigation, measures to avoid issues in further production. The template of NCR is provided from the Company. The Contractor has to organize a review meeting on the NCR and shall explain it to the Company.

A non-conformity can be a possible reason for a rejection of the deliverable by the Company. In case improvement/mitigation measures require change of the design or QIPP for further production steps, an Engineering Change Request (ECR) shall be submitted and approved by the Company. After repair or mitigation, updated as-built drawings and 3D model shall be submitted by the Contractor, if there are any changes. NCRs have to be filed for each affected unit individually and these cannot affect the other series production units. In this case, the relevant ECRs are required. NCRs have to be formally approved by the Company before any work on the affected units. The minimum timeframe needed by the Company to approve an NCR is two weeks.

6.2. **Quality assurance topics**

Short descriptions on quality assurance topics of the units are given. Details of each inspection and testing are described in the relevant documents (specifications, technical guidelines) and need to follow the best engineering practice. The scope of the FAT is explicitly given in Annex 01 of F-DS-SCM-en-MT_0152. The QIPP and templates of test protocols, which is defined in and referred from QIPP, must be prepared with criteria by the Contractor and approved by the Company before starting the production of the units (typically at the FDR).

6.2.1. Documentation and certificates

The units are operated under cryogenic temperature, high radiation, electric field, magnetic field, and vacuum conditions. Material certificates (e.g. EN 10204 type 3.1, Pressure Equipment Directive and AD 2000 relevant certificates) of the unit parts as well as welding & brazing certificates shall be submitted by the Contractor. The necessary examination of the materials to prove the property or functionality (for example, dielectric strength measurement of insulation material at low temperature, irradiation hardness) shall be conducted by the Contractor.

The operation manual (in German language), risk analysis documents, declaration of conformity or a complete set of documents needed for the declaration of conformity (CE) shall be submitted by the Contractor in agreement with the Company.

All documents related to the units should have an official identification number (CID) and name defined and provided by the Company. The Contractor's internal identification number or naming only is not allowed. The official CID shall be used in communication between the Contractor and the Company.

6.2.2. Workshop environment and condition, cleanness

In order to avoid fatal contamination into the unit, a clean workshop environment is essential. Especially for the coil winding and assembly, high level cleanness is required (e.g. an over pressured room compared to atmosphere). The Contractor has to prepare a proper space for the production. The workers in the room have to wear clean clothes, gloves, and overshoes. For the other operations, it is also necessary to keep cleanness of the working place. The Contactor shall assure cleanness of the tooling and the parts, objects in the production process, and the produced items. For example, all tubes have to be clean and dust free.

6.2.3. Visual inspection

Visual inspections shall be planned and executed in the steps of the production as well as before the shipments to GSI, to prevent contamination, to detect and avoid use of parts and components with damage, change of colour (property), corrosion of metal, deformation and further defects. Photographic and video documentation and reporting shall be defined in the quality control and production plan (typically at FDR).

6.2.4. Mechanical inspection

Measurements of the dimension with appropriate and calibrated tools shall be executed for the materials and assembled components in the steps of the production. Photographic and video documentations with a measure have to be reported. The details shall be defined in the production and control plan (typically at FDR).

The document Unit-Production-CheckSizes.pdf attached to F-DS-SCM-en-MT_0152, Annex 01 (see Sect. 7), shows sizes and dimensions that are particularly important for the functionality of the units. The document proposes a way of reporting the checks of these sizes and dimensions. The document does not relax the requirements imposed by the drawings. For critical sizes and relations 3D

information of the measured points needs to be delivered by the Contractor. The final scope has to be agreed in the FDR. For instance, adjustments may be necessary for each unit type due to the different configurations.

Especially, given mechanical tolerances in the drawings shall be proved and reported by the Contractor. The contractor shall introduce dimensional measurement steps in the manufacturing process. The measurement process and document templates with acceptance criteria for the reporting shall be agreed with the Company (typically at FDR). The Contractor shall execute the measurements and report to the Company with agreed reporting document templates.

Details are described in Annex 01 of F-DS-SCM-en-MT_0152. In case of conflict, the information given there shall be leading.

6.2.5. **Vacuum**

The units are stored in a cryostat vacuum vessel and operated under insulation vacuum condition (level of 10^{-7} mbar). The following points on the units have to be carefully checked:

- Mechanical structure must be optimised to have minimum impact on the pumping speed (e.g. to avoid pinholes, hidden volumes).
- No residuals of materials which lead to outgassing.

Details are described in the relevant technical guidelines, see Section 7, and in Annex 01 of F-DS-SCM-en-MT_0152. In case of conflict, the information given there shall be leading.

6.2.6. **Pressure**

The units shall be designed and manufactured according to PED (Pressure Equipment Directive) and AD 2000 including an appropriate documentation (e.g. with respect to test documentation and material certificated, etc.). Tightness of the helium containments, pipes, tubes (cables, busbars, yoke cooling, connecting tubes, process pipes, voltage breakers) and joints shall be checked. The design pressure is 20 bar absolute. Thus, a test pressure of 28.6 bar has to be applied, which equals 1.43 times the design pressure. The Contractor shall subject the units to the relevant pressure tests in compliance with PED and AD 2000 as well as requirements by the Company. Details of the test procedures are described in the relevant guidelines, see Section 7. The test and results shall be reported. Further details are given in Annex 01 of F-DS-SCM-en-MT_0152. In case of conflict, the information given there shall be leading.

6.2.7. **Hydraulic resistance**

Hydraulic property of the unit shall be checked to assure proper functionality of the cooling circuits. A proof of the required helium mass flow through the cooling channel has to be carried out at room temperature according the relevant technical guideline, see Section 7. The Contractor has to measure a pressure drop along the cooling circuit with an inlet pressure $\Delta P = 0.1 – 0.2$ bar above ambient. In same type of the units, unit-to-unit spread of the flow rate shall be less than 10%.

The contractor needs to manufacture all restrictors (MG-1015867-P-*) from a single batch of capillary tubing. On request of the Company the restrictor length needs to be adjusted by the Contractor after the cold test of the first unit of each type.

Further details are given in Annex 01 of F-DS-SCM-en-MT_0152. In case of conflict, the information given there shall be leading.

6.2.8. **Electrical integrity**

The following category of electrical tests have to be done in appropriate manufacturing steps. The details of the tests are described in the relevant technical guidelines and in Annex 01 of F-DS-SCM-en-MT_0152. In case of conflict, the information given there shall be leading.

6.2.8.1. **Impedance test of the coil**

The impedance of the coil shall be measured before and after assembly with the magnet yoke. The measurement shall be done with at least 3.5 digit RLC meter. The following parameters shall be protocolled:

- DC Resistance of the coil
- Inductance of the coil alone at 100 Hz and at 1 kHz
- Inductance of the magnet (coil + yoke) at 100 Hz and at 1 kHz

6.2.8.2. **High voltage test of the coil**

In order to check insulation faults of the live-circuit to ground and live-circuit to another live-circuit, and to instrumentation circuits, the HV test shall be performed. During the HV test the magnet terminals shall be connected together. The positive lead of the HV tester shall be connected to the magnet coil. The negative lead of the tester shall be connected to the electrical ground, e.g. yoke. The insulated helium tube, the outer frame of the terminal boxes and other circuits (if any, e.g. temperature sensors, heaters, etc.), shall be connected to the ground during the test.

The maximum test voltage is defined by the relevant technical guideline, typically 2 times of maximum operating voltage (including quench case). Details shall be agreed with the Company.

The insulation resistance and leakage current shall be recorded for each test. Graphical and tabular record of insulation resistance vs time and leakage current vs. time shall be included in the protocol. The result of the HV test is acceptable when at each test the insulation resistance is above 1.0 GΩ and the resistance vs. time waveform does not reveal dramatic changes or fluctuations.

The details of the tests are described in the relevant technical guidelines and in Annex 01 of F-DS-SCM-en-MT_0152. In case of conflict, the information given there shall be leading.

6.2.8.3. Inter-turn insulation test of the coil (surge test)

Inter-turn insulation faults of the coil shall be checked by a surge test (capacitor discharge test) with proper HV discharge equipment. The discharge waveforms (coil voltage and coil current) shall be recorded and attached to the protocol. The oscillation frequency and the Q-factor shall be calculated, protocolled and compared to the theoretical values and already measured values on the other magnets. If the discharge waveforms are distorted, it means that there might be an inter-turn insulation fault, which should be reported.

The details of the tests are described in the relevant technical guidelines and in Annex 01 of F-DS-SCM-en-MT_0152. In case of conflict, the information given there shall be leading.

6.2.8.4. Low voltage test

The temperature sensors and heaters shall be tested to prove electrical insulation to ground and to other related circuits. The test shall be performed at 50 V with a duration of 60 seconds for the sensors, at 100 V with a duration of 60 seconds for the heaters. During the LV test terminals of the sensors shall be connected together. The positive lead of the tester shall be connected to the sensor terminals. The negative lead of the tester shall be connected to the electrical ground, e.g. yoke. Other circuits, e.g. other magnet coils or bus-bars, other temperature sensors, other heaters, etc. shall be connected to the ground during the test. The result of the LV test is positive when at each test the insulation resistance is above 100 MΩ.

The details of the tests are described in the relevant technical guidelines and in Annex 01 of F-DS-SCM-en-MT_0152. In case of conflict, the information given there shall be leading.

6.2.8.5. Sensor alive test and voltage tap continuity test

All resistive temperature sensors shall be measured with 4-wire method. The obtained resistance shall be compared with the calibration data. The protocol shall contain name of the sensor, its CID, measured resistance and expected resistance.

Voltage tabs are attached to the live-circuits. Order of the voltage taps along the circuit is crucial for quench detection. The connection to the circuit and the order along the circuit shall be confirmed.

The details of the tests are described in the relevant technical guidelines and in Annex 01 of F-DS-SCM-en-MT_0152. In case of conflict, the information given there shall be leading.

6.2.9. Material properties

Critical material properties, such as the permeability of metal used for the yoke production shall be measured before production (incoming inspection) and after critical production processes such at heat treatment or welding.

6.3. **Quality assurance inspection points in the production timeline and scope of FAT**

The unit production can be divided into following sub production steps:

- Unit
  - Magnet
    - Cable production
    - Coil production
    - Yoke production
    - Magnet assembly and instrumentation
  - Busbar
    - Cable production
    - Busbar production and instrumentation
  - Unit assembly
    - Assembly of corrector magnets to the main quadrupole magnet
    - Busbar installation
    - Process pipe installation

Above each step requires inspections

- of material and production preparation (tooling etc.)
- during production
- for acceptance
- for and after storage

For example, before the coil production, the cable, which was stored after the cable production and acceptance inspection, are inspected again as base material for the coil after storage. During the coil production, the dimension of the coil is checked. The produced coil is checked and accepted for the next step, the magnet assembly, then stored under proper condition.

Inspection in each step shall be defined according to Sect. 6.2. For example, the assembled magnet after storage shall be checked with the documentation and the certificates, executed visual inspection and possibly some electrical test and then prepared for the unit assembly. Detailed timeline shall be arranged in the Quality Control and Production Plan.

For acceptance of the units, the units need to be subjected to the Factory Acceptance Tests (see also Sect. 5.3.2). The scope of the FAT is defined in the Annex 01 of F-DS-SCM-en-MT_0152, and in the corresponding specifications (see Sect. 7)

7. Related Documents

7.1. Specifications and technical guidelines

Type	Mandatory/ Recommendation	Document ID	title	about	EDMS-ID
General specification	M	F-GS-PMO-en	General specification	general information	1365092
Common specification	R	F-CS-MT-04e	Common specification of the cooling system of the superconducting SIS100 magnets	Cooling hydraulic connections	1274168
Detailed specifications	M	F-DS-SCM-en-MT_0152	SIS100 Quadrupole Units Production (the document in hand)	SIS100 unit production	2913884
	M	F-DS-SCM-en-MT_0152, Annex 01	Acceptance test description (Annex of the specification)	FAT testing and criteria, SAT criteria	2913884
	M	F-DS-SCM-en-MT_0152, Amendment 01	SIS100 Quadrupole Units Production, Detailed Specification Amendment	SIS100 unit production	2913884
	M	F-DS-MT-80e	Bus-Bars and Voltage Taps in the SIS100 Quadrupole Modules	Electric connections	1447831
	M	F-DS-MT-71e	Cooling system of the regular arc quadrupole modules for SIS100	Cooling hydraulic connections	1275675
	M	F-DS-MT-83e	Cooling System of the Arc Termination Quadrupole Modules for SIS100	Cooling hydraulic connections	1532603
	M	F-DS-MT-79e	Cooling System of the Quadrupole Modules in the Straight Sections of SIS100	Cooling hydraulic connections	1346794
	M	F-DS-MT-108e	Instrumentation for SIS100 Quadrupole-Modules	Instrumentation	1561225
	M	F-DS-MT-107e	Specifications of quadrupole doublet module	SIS100 doublet module	1533009
	R	F-DS-MT-86e	Testing SIS100 Quadrupole Unit Magnets	SIS100 unit cold testing	1366284
Technical guidelines	M	F-TG-A-3.68e	FAIR related coordinate systems	Alignment	1172944
	R	F-TG-A-3.18e	Mechanical tolerances of quadrupoles	Alignment	1172931
	M	F-TG-QUA	Technical Guideline for Welding Practices	Welding	2383347
	M	F-DO-QUA	Requirements for Welding Companies	Welding	2383347
	M	F-TG-B-01e	Material Selection and Radiation	Material	1173073
	M	F-TG-S-2.21e	Radioactive radiation of synthetic materials	Material	1172955
	M	F-TG-K-2.35e	Steel Materials for Pressurized Cryogenic Components	Material	1172134
	M	F-TG-K-3.57e	Adhesive Tapes for Cryogenic Purposes	Material	1172147

	M	F-TG-B-02e	Data Exchange Guideline Part 1: Basis Document	Data management	1229366
	M	F-TG-B-03e	Data Exchange Guideline Part 2: Short Infos and Checklists	Data management	1259954
	M	F-TG-MDS-de-KRL	New: Technical Guideline Konstruktionsrichtlinie (KRL)	Data management	1229367
	M	F-TG-K-10.14e	Documentation of Results from Mechanical and Thermo-Mechanical FEM-Simulations	Data management	1172855
	M	F-TG-MT-2.39e	Local coordinate axes to be used for magnet drawings	Data management	1173081
	M	F-TG-B-05e	Permanent Tagging and Labelling of Components	Data management	1229368
	M	F-TG-MT-8.0e	Label plates used for designation of components in superconducting magnets	Data management	1382612
	M	F-TG-ET-01e	Electrical Design Rules and Regulations	Electrical issues	1172862
	M	F-TG-MT-01e	DC High Voltage Insulation Tests for SC Magnets	Electrical issues	1173079
	M	F-TG-K-7.23e	He Leak Testing of Cryogenic Tubing	Pressure, vacuum issues	1172844
	M	F-TG-K-7.24e	Pressurized Leak Testing of Cryogenic Tubing	Pressure, vacuum issues	1172845
	M	F-TG-K-7.26e	Flow Rate Test for Cryogenic Processing Pipes	Pressure, vacuum issues	1172846
	M	F-TG-K-7.27e	Residual Moisture Test for Cryogenic Processing Pipes	Pressure, vacuum issues	1172847
	M	F-TG-V-6.2e	Cleaning of Vacuum Components	Pressure, vacuum issues	1172895
	R	F-TG-K-52.0e	Safety Devices for Cryogenics	Pressure, vacuum issues	1172861
	R	F-TG-MT-7.6e	Mechanical approval magnets	Mechanical issues	1173106
	R	F-TG-MT-7.7e	Mechanical approval quadrupoles	Mechanical issues	1173107
	R	F-TG-MT-7.9e	Standard program for magnetic measurement quadrupole	Mechanical issues	1173109
	R	F-TG-K-3.61e	Thermal Links and Interceptions in Cryogenic Applications	Mechanical issues	1172148

7.2. **Drawings**

The colour in the table is used to highlight identical drawings.

			Quantity principal	upstream unit	Unit	Corrector magnet (CV/MC)	QD magnet	Busbar	He supply pipe
	standard								
1	**2.123**	15		**QDB**	MG-1047000-A-V01	-	MG-1034192-A-V04	-	-
2	**2.4**	5		**QDBb**	MG-1034781-A-000	-	MG-1034192-A-000	MG-1040582-A-V01	MG-1020296-A-V02
3	2.5	6		**VQD**	MG-1033909-A-000	MG-1036674-A-000	MG-1033842-A-000	MG-1040582-A-000	MG-1020296-A-V01
4	1.6A	12		**BQD**	MG-1021461-A-000	-	MG-1033842-A-000	MG-1040582-A-000	MG-1020296-A-V01
5	1.7B	12		**VQD**	MG-1033909-A-000	MG-1036674-A-000	MG-1033842-A-000	MG-1040582-A-000	MG-1020296-A-V01
6	2.8C	12		**BQD**	MG-1021461-A-000	-	MG-1033842-A-000	MG-1040582-A-000	MG-1020296-A-V01
7	**2.9D**	12		**BQD**	MG-1021461-A-000	-	MG-1033842-A-000	MG-1040582-A-000	MG-1020296-A-V01
8	**1.E**	5		**MQDb**	MG-1047020-A-000	MG-1013181-A-V02	MG-1034192-A-V03	MG-1040582-A-V02	MG-1020296-A-V04
	special								
9	**2.13s**	2		**QDB**	MG-1047000-A-V01	-	MG-1034192-A-V04	-	-
10	**2.4x**	1		**QDBx**	MG-1124761-A-000	-	MG-1034192-A-V06	MG-1040582-A-V03	To be prepared
11	**1.Ei**	1		**MQDi**	MG-1044401-A-000	MG-1013181-A-V02	MG-1034192-A-V03	To be prepared	To be prepared
variation	**11**			**7**	**7**	**2**	**6**	**5**	**5**
total quantity		83							

			Quantity principal	downstream unit	Unit	Steering magnet (ST)	F1 magnet	F2 magnet	Corrector magnet (MC/CH/GJ)	Busbar	He supply pipe
	standard										
1	**2.123**	15		**SF2**	MG-1058066-A-V01	MG-1043544-A-000	-	MG-1034192-A-V08	-	-	-
2	**2.4**	5		**SF2Mb**	MG-1034687-A-000	MG-1043544-A-000	-	MG-1034192-A-V01	MG-1013181-A-V02	MG-1040801-A-V01	MG-1020291-A-V02
3	2.5	6		**SF2B**	MG-1034061-A-000	MG-1043544-A-000	-	MG-1033842-A-V01	-	MG-1040801-A-000	MG-1020291-A-V01
4	1.6A	12		SF1H	MG-1040358-A-000	MG-1043544-A-000	MG-1033842-A-V02	-	MG-1036674-A-000	MG-1043327-A-000	MG-1020291-A-V01
5	1.7B	12		**SF1B**	MG-1039632-A-000	MG-1043544-A-000	MG-1033842-A-V02	-	-	MG-1043327-A-000	MG-1020291-A-V01
6	2.8C	12		SF2H	MG-1021355-A-000	MG-1043544-A-000	-	MG-1033842-A-V01	MG-1036674-A-000	MG-1040801-A-000	MG-1020291-A-V01
7	**2.9D**	12		**SF2J**	MG-1021652-A-000	MG-1043544-A-000	-	MG-1033842-A-V01	MG-1015130-A-V02	MG-1040801-A-000	MG-1020291-A-V05
8	**1.E**	5		**SF1Bb**	MG-1047042-A-000	MG-1043544-A-000	MG-1034192-A-V02	-	-	MG-1043327-A-V01	MG-1020291-A-V06
	special										
9	**2.13s**	2		**SF2**	MG-1058066-A-V01	MG-1043544-A-000	-	MG-1034192-A-V08	-	-	-
10	**2.4x**	1		**SF2Mx**	MG-1124829-A-000	MG-1043544-A-V01	-	MG-1034192-A-V07	MG-1013181-A-V02	To be prepared	To be prepared
11	**1.Ei**	1		**SF1Bi**	MG-1125284-A-000	MG-1043544-A-000	MG-1034192-A-V10	-	-	MG-1043327-A-V02	To be prepared
variation	**11**			10	10	2	4	4	3	6	6
total quantity		83									