Document Title:	**Bus-Bars and Voltage Taps in the SIS100 Quadrupole Modules**
Description:	Detailed specification for bus-bars and voltage taps in the SIS100 quadrupole modules (2.123, 2.13s, 2.4, 2.4x, 2.5, 1.6A, 1.7B, 2.8C, 2.9 D, 1.E and 1.Ei)
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Abstract

This document is the detailed specification for bus-bars and voltage taps in SIS100 quadrupole modules (all types). The aim of this document is to give the 3D arrangement of main bus-bars, describe the electrical connections of quadrupole and corrector coils and show the exact location of voltage taps that shall be installed on quadrupole magnets, main bus-bars, corrector magnets, corrector bus-bars, injection/extraction quadrupole magnets and local current leads.

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1 Purpose and classification of the document

The purpose of this detailed specification is to provide information concerning the 3D arrangement of main bus-bars, to describe the electrical connections of quadrupole and corrector coils and to show the exact location of voltage taps that shall be installed on quadrupole magnets, main bus-bars, corrector magnets, corrector bus-bars and local current leads. Before reading this specification one shall acquaint with the General Specification for the FAIR Accelerator Facility Project [1].One shall also get acquainted with detailed specification concenring the delivery and integration of quadrupole units (QDM 2.5 example) [2], cooling systems [6, 7, 8], magnets [9, 10, 11, 12, 13], local current leads [14], testing [21, 20] and with technical guidelines [15, 16, 17, 18, 19].

2 Abbreviations, terms and definitions

Table 1: Abbreviation, terms and definitions

Abb., Term	Definition
GSI	GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany
FAIR	International Facility for Antiproton and Ion Research
SIS100	Schwerionensynchrotron (en: Heavy ion synchrotron) 100 Tm
QDM	Quadrupole Doublet Module
F1	SIS100 Focusing Quadrupole Magnet, Family 1 (superconducting)
F2	SIS100 Focusing Quadrupole Magnet, Family 2 (superconducting)
QD	SIS100 Defocusing Quadrupole Magnet (superconducting)
CS (magnet)	SIS100 Chromaticity Sextupole Magnet (general abbreviation) (superconducting)
CH	SIS100 Chromaticity Sextupole Magnet (horizontal polarization) (superconducting)
CV	SIS100 Chromaticity Sextupole Magnet (vertical polarization) (superconducting)
TCV	Terminal Box for CV
TCH	Terminal Box for CH
ST	SIS100 Steering Magnet (superconducting)
SH	SIS100 Steering Magnet, Horizontal Coil (superconducting)
SV	SIS100 Steering Magnet, Vertical Coil (superconducting)
TSH	Terminal Box for SH
TSV	Terminal Box for SV
MC	SIS100 Multipole Corrector Magnet (superconducting)
MQ	SIS100 Multipole Corrector Magnet, Quadrupole Coil (superconducting)
MS	SIS100 Multipole Corrector Magnet, Sextupole Coil (superconducting)
MO	SIS100 Multipole Corrector Magnet, Octupole Coil (superconducting)
TMQ	Terminal Box for MQ
TMS	Terminal Box for MS
TMO	Terminal Box for MO
QJ	SIS100 Gamma-t Jump Quadrupole Magnet (normal-conducting)
LQ	SIS100 Injection/Extraction Quadrupole Magnet (Low current Quadrupole, superconducting)
TLQX or TLQY	Terminal Box for LQ

Abb., Term	Definition
MCL	Main Current Lead, 14 kA Cu+HTS current lead
LCL	Local Current Lead, 250 A Cu+HTS current lead
BPM	Beam Position Monitor
COL	Cryo-Ion Catcher (Collimator)
DT	Drift Tube
B-CWT	Beam Vacuum Cold-Warm Transition
CAP	Cryo-Adsorption Pump
R-CWT	Roughing Cold-Warm Transition
FoS	”First of Series”
PDR	Preliminary Design Review
FDR	Final Design Review
FAT	Factory Acceptance Test
SAT	Site Acceptance Test
Test Objects	Quad. modules/units and their corresponding parts to be tested during FAT and SAT
Quench	A transition of the superconductor from the superconducting to the normal conducting state.
Cu	Copper
LTS	Low Temperature Superconductor
HTS	High Temperature Superconductor
NCS	Non-Connection Side of the coil
CS (coil)	Connection Side of the coil
US	Beam UpStream
DS	Beam DownStream
Valtage tap (Vtap)	A place at the superconducting cable (i.e. at the coil, main bus-bar or corrector bus-bar) where the voltage tap wire will be soldered. Voltage taps are used by the quench detection system. Voltage taps are located at places where the electrical potential needs to be measured
Valtage tap wire	A special wire which connects the voltage tap with the electrical socket located at the instrumentation flange

Convention for the drawings of superconducting magnets are given in [3]. It includes the local coordinates described in Fig. 1.

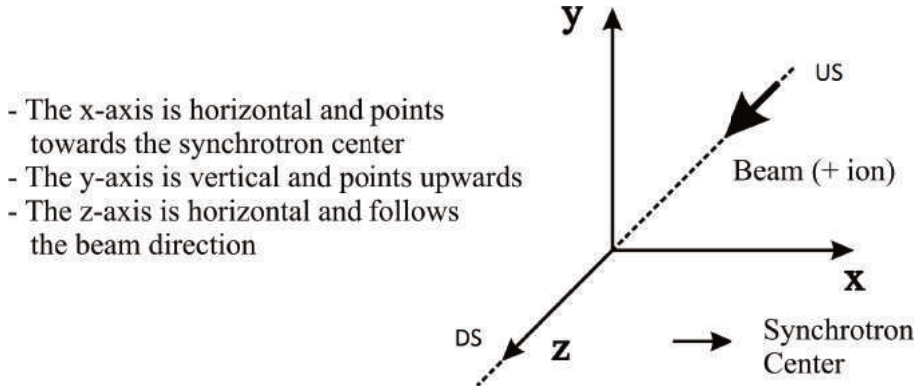


Figure 1: Local coordinates to be used in drawings and sketches of superconducting magnets (courtesy of E. Floch).

3 Scope of technical system

3.1 System Overview

The SIS100 synchrotron is divided into six sectors. Each sector consists of 14 cells named 1, 2, . . . , 9, A (10), B (11), C (12), D (13), E (14). Cells 1,2 and 3 form a straight section, while cells from 4 to E (14) form an arc section. Each cell (except cell 2 in sector 5) contains one quadrupole doublet module (QDM). The meaning of the QDM's nomenclature is explained in Fig. 2. The scheme of the SIS100 machine is presented in Fig. 3.

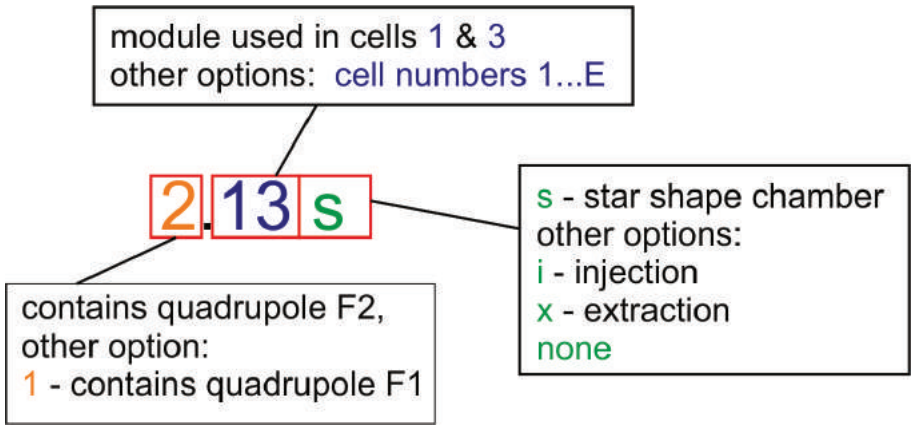


Figure 2: Explanation of QDMs names.

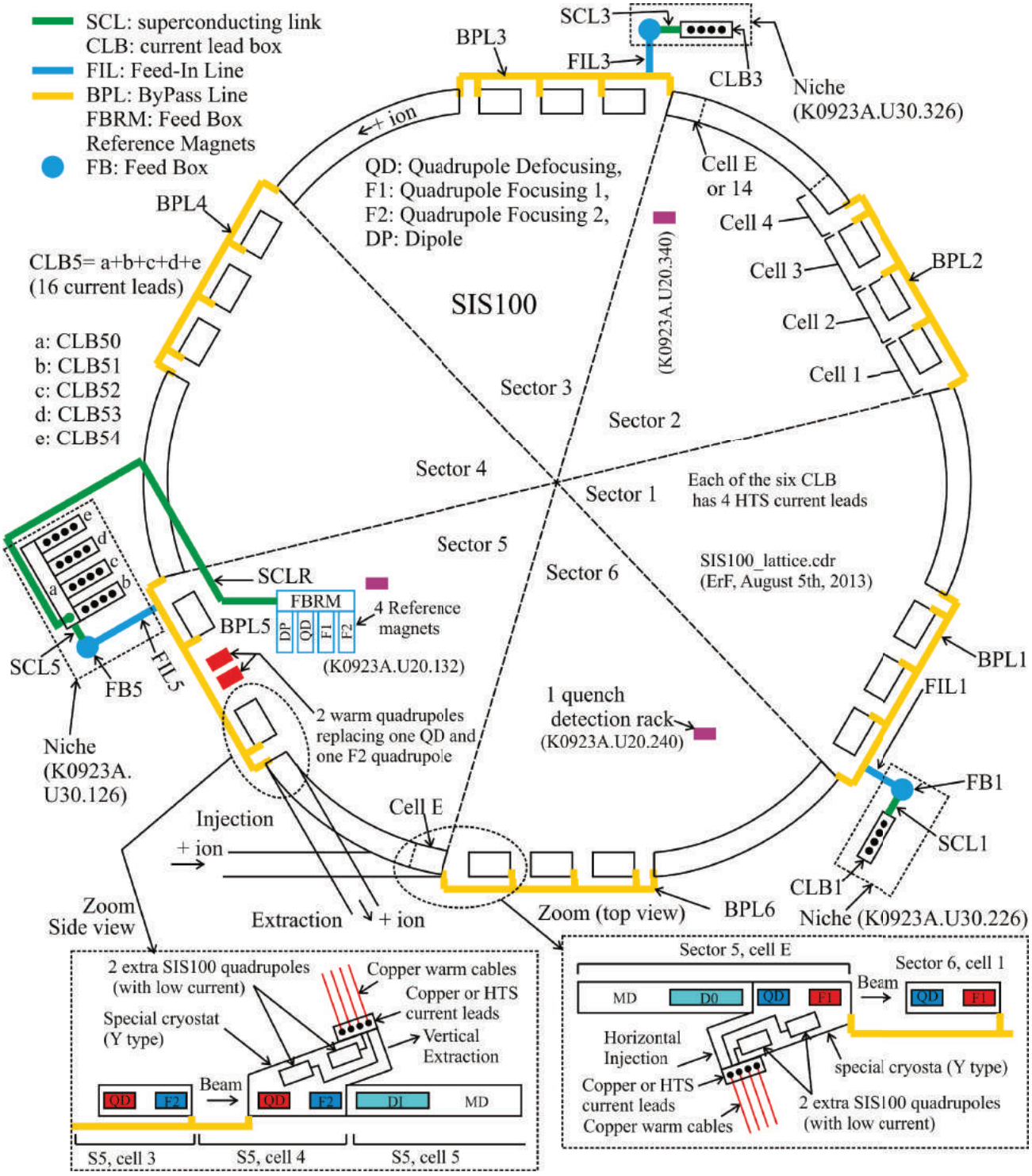


Figure 3: Sectors and cells in the SIS100 machine (courtesy of E. Floch).

There are 11 QDM types. Concerning the main bus-bar arrangement, one can distinguish five groups:

- (1) The straight section modules: 2.123 (sectors: 1, 2, 3 ,4 and 6) and 2.13s (in sector 5 only) – direct connection of bus-bars and coils. Occurs in US unit QDB and DS unit SF2.
- (2a) The regular arc section modules with F1 quadrupole magnet: 1.6A & 1.7B (in sectors: 1, 2, 3 ,4, 5 and 6) – standard bus-bars. Occurs in US units: VQD & BQD and DS units: SF1H & SF1B.
- (2b) The regular arc section modules with F2 quadrupole magnet: 2.5, 2.8C & 2.9D (in sectors: 1, 2, 3 ,4, 5 and 6) – standard bus-bars. Occurs in US units: VQD & BQD and DS units: SF2H, SF2J & SF2B.
- (3) The end of the arc section modules: 1.E (in sectors: 1, 2 ,3 ,4, and 6) and 1.Ei (injection, Y-cryostat, in sector 5 only) – special bus-bars, longer at the US part (due to MC). Occurs in US units: MQD & MQDi and DS units: SF1Bb & SF1Bi.
- (4) The beginning of the arc section 2.4 (sectors: 1, 2, 3, 4 and 6) – special bus-bars, longer at the DS part (due to MC). Occurs in US unit QDBb and DS unit SF2M.
- (5) The extraction module 2.4x (Y-cryostat, in sector 5 only) – special bus-bars, longer at the DS part (due to MC) and modified because of the collision with extraction quadrupole. Occurs in US unit QDBx and DS unit SF2Mx.

Fig. 4 shows parts of the QDM 2.5 as an example. This module consists of two units: DS unit and US unit. The DS unit consists of F2 quadrupole magnet that includes F2o bus-bar, F2i bus-bar, F1 bus-bar pair, steering magnet (ST) and steerer bus-bar. The US unit consists of QD quadrupole magnet that includes QDo bus-bar, QDi bus-bar, DP bus-bar pair, vertical chromaticity sextupole (CV) and sextupole bus-bar. In the 2.5 module, there are three pairs of local current leads (LCL). Two pairs for ST and one pair for CV.

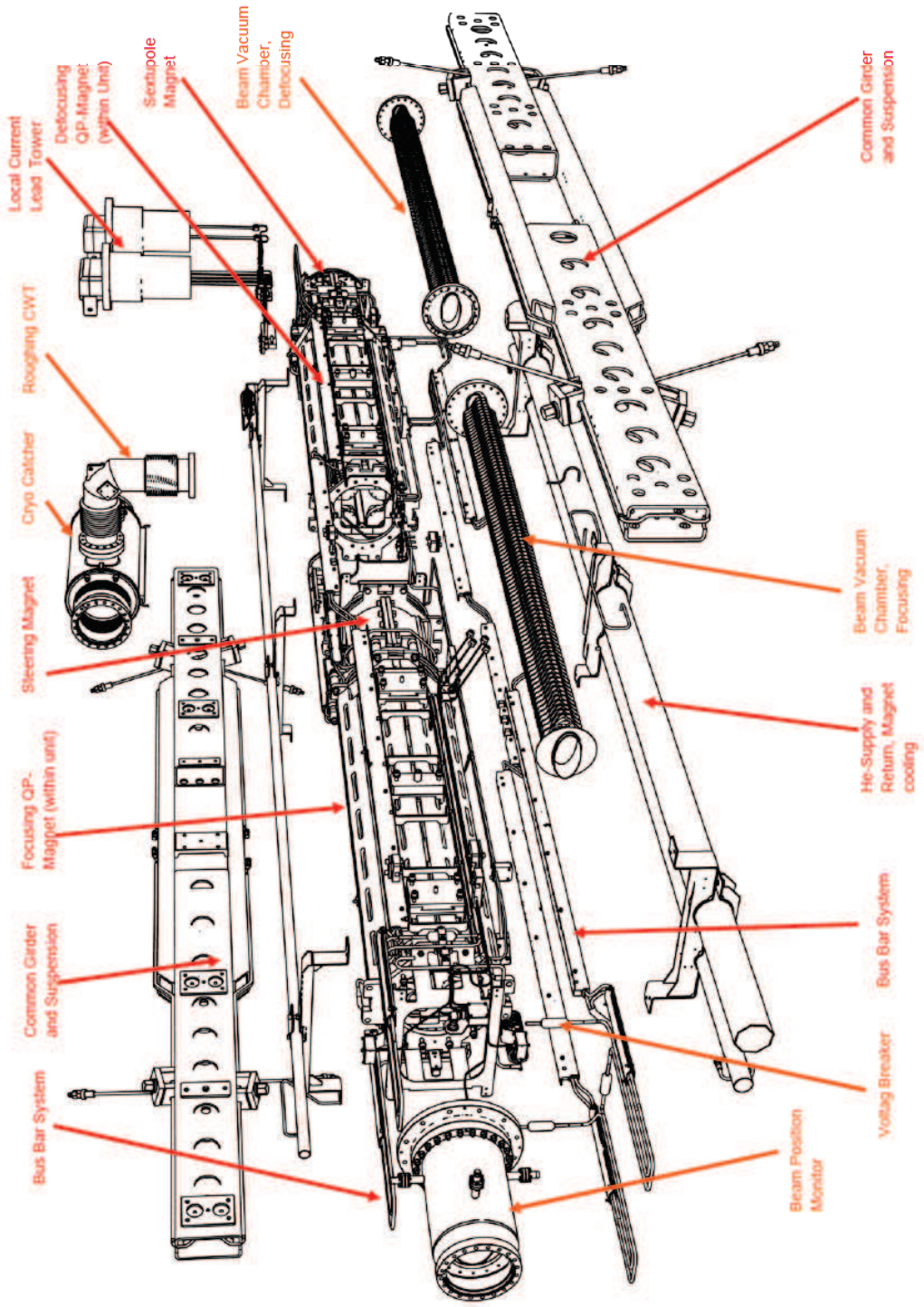


Figure 4: 2.5 quadrupole doublet made of 2 units.

3.2 Content of Delivery and Spare Parts

Table 2 presents total number of copper clamps (used for voltage tap installation on the main magnets and their bus-bars), number of voltage tap sockets (installed in the instrumentation flanges) and estimated length of the voltage tap cable.

Number of magnets, corresponding bus-bars and spare components is presented in table 3. The quadrupole coils shall be manufactured in conjunction with the outer bus-bar (one piece of cable) and assembled together with the inner bus-bar. Bus-bar pairs shall be baked together. Bus-bars that are passing through QDM without connection to the quadrupole shall also be baked in pairs.

Table 2: Voltage taps wire, clamps and sockets

Component	Quantity	Spare
7-pin socket DEE 106 A007-130	166	0
8-pin socket DEE 106 A019-130	83	0
19-pin socket DEE 107 A015-130	252	0
voltage tap wire* multi-strand Cu wire, 5 kV, cross-section 0.12-0.20 mm^2	37 km	3 km
voltage tap clamps	1660	100

* – Recommended voltage tap wire: HH2619-LH (AXON' KABEL GmbH)

Table 3: Content of delivery and spare parts

Component	Occurs in unit	Quantity	Spare
F2 coil + bus-bars in QDMs 2.123 & 2.13s	DS: SF2	17	3
QD coil + bus-bars in QDMs 2.123 & 2.13s	US: QDB	17	3
QD coil + bus-bar QDo in QDMs 1.6A, 1.7B 2.5, 2.8C & 2.9D	US: VQD & BQD	54	10
bus-bar QDi in QDMs 1.6A, 1.7B 2.5, 2.8C & 2.9D	US: VQD & BQD	54	2
bus-bar DPo in QDMs 1.6A, 1.7B 2.5, 2.8C & 2.9D	US: VQD & BQD	54	2
bus-bar DPi in QDMs 1.6A, 1.7B 2.5, 2.8C & 2.9D	US: VQD & BQD	54	2
F2 coil + bus-bar F2o in QDMs 2.5, 2.8C & 2.9D	DS: SF2B, SF2H & SF2J	30	5
bus-bar F2i in QDMs 2.5, 2.8C & 2.9D	DS: SF2B, SF2H & SF2J	30	1
bus-bar F1o in QDMs 2.5, 2.8C & 2.9D	DS: SF2B, SF2H & SF2J	30	1
bus-bar F1i in QDMs 2.5, 2.8C & 2.9D	DS: SF2B, SF2H & SF2J	30	1
F1 coil + bus-bar F1o in QDMs 1.6A & 1.7B	DS: SF1H & SF1B	24	7
bus-bar F1i in QDMs 1.6A & 1.7B	DS: SF1H & SF1B	24	1
bus-bar F2o in QDMs 1.6A & 1.7B	DS: SF1H & SF1B	24	1
bus-bar F2i in QDMs 1.6A & 1.7B	DS: SF1H & SF1B	24	1
F1 coil + bus-bar F1o in QDMs 1.E & 1.Ei	DS: SF1Bb & SF1Bi	6	1
bus-bar F1i in QDMs 1.E & 1.Ei	DS: SF1Bb & SF1Bi	6	0
bus-bar F2o in QDMs 1.E & 1.Ei	DS: SF1Bb & SF1Bi	6	0
bus-bar F2i in QDMs 1.E & 1.Ei	DS: SF1Bb & SF1Bi	6	0
QD coil + bus-bar QDo in QDMs 1.E & 1.Ei	US: MQD & MQDi	6	1
bus-bar QDi in QDMs 1.E & 1.Ei	US: MQD & MQDi	6	0
bus-bar DPo in QDMs 1.E & 1.Ei	US: MQD & MQDi	6	0
bus-bar DPi in QDMs 1.E & 1.Ei	US: MQD & MQDi	6	0
F2 coil + bus-bar F2o in QDM 2.4	DS: SF2M	5	1
bus-bar F2i in QDM 2.4	DS: SF2M	5	0
bus-bar F1o in QDM 2.4	DS: SF2M	5	0
bus-bar F1i in QDM 2.4	DS: SF2M	5	0
QD coil + bus-bar QDo in QDM 2.4	US: QDBb	5	1
bus-bar QDi in QDM 2.4	US: QDBb	5	0
bus-bar DPo in QDM 2.4	US: QDBb	5	0
bus-bar DPi in QDM 2.4	US: QDBb	5	0
F2 coil + bus-bar F2o in QDM 2.4x	DS: SF2Mx	1	1
bus-bar F2i in QDM 2.4x	DS: SF2Mx	1	0
bus-bar F1o in QDM 2.4x	DS: SF2Mx	1	0
bus-bar F1i in QDM 2.4x	DS: SF2Mx	1	0
QD coil + bus-bar QDo in QDM 2.4x	US: QDBx	1	1
bus-bar QDi in QDM 2.4x	US: QDBx	1	0
bus-bar DPo in QDM 2.4x	US: QDBx	1	0
bus-bar DPi in QDM 2.4x	US: QDBx	1	0

Component	Quantity	Spare
CV & CH coils	18+24= 42	9
ST nested coils	83	8
MC nested coils	12	3
Terminal boxes for 28-strand cable	42(CS)+166(ST)+36(MC)=244	2
QJ coil Cu current leads for QJ Cu 2-wire-cable for QJ	12 12 pairs NR	NR NR NR
LQ coil	4	1
Terminal boxes for 21-strand cable	4	1
LCL*	244(CS,ST,MC)+8(LQ)=252 pairs	30 pairs
28-strand corrector cable for bus-bars 21-strand corrector cable for bus-bars	1000 m 30 m	250 m 10 m
Technical documentation (in English) concerning: • main bus-bar production • corrector bus-bar production • used voltage tap wire • connections in terminal boxes • test reports & protocols (see section 6)		

NR - Not Relevant in terms of this document

* **- the cold terminal of LCLs is a part of the unit**

4 System specification

4.1 Quadrupole Doublet Modules and Corresponding Quadrupole Units

The QDM types and their quantity are presented in Table 4.

Table 4: Quadrupole Doublet Modules and Corresponding Quadrupole Units

QDM	US unit	DS unit	Sector	Quantity	Comment
2.123	QDB	SF2	1, 2, 3, 4, 6	15	straight section
2.13s	QDB	SF2	5	2	straight section with star shape VC
2.5	VQD	SF2B	1, 2, 3, 4, 5, 6	6	regular arc section with F2
2.8C	BQD	SF2H	1, 2, 3, 4, 5, 6	12	regular arc section with F2
2.9D	BQD	SF2J	1, 2, 3, 4, 5, 6	12	regular arc section with F2
1.6A	BQD	SF1H	1, 2, 3, 4, 5, 6	12	regular arc section with F1
1.7B	VQD	SF1B	1, 2, 3, 4, 5, 6	12	regular arc section with F1
2.4	QDBb	SF2M	1, 2, 3, 4, 6	5	beginning of the arc section
2.4x	QDBx	SF2Mx	5	1	beginning of the arc section (extraction)
1.E	MQD	SF1Bb	1, 2, 3, 4, 6	5	end of the arc section
1.Ei	MQDi	SF1Bi	5	1	end of the arc section (injection)

In QDMs: 2.5, 2.8C, 2.9D, 2.4 and 2.4x:

- the US unit contains QD quadrupole and QDo bus-bar[1], QDi bus-bar, DP bus-bar pair (DPo and DPi) and corresponding corrector magnet or magnets (according to Table 4);
- the DS unit contains F2 quadrupole and F2o bus-bar[1], F2i bus-bar, F1 bus-bar pair (F1o and F1i) and corresponding corrector magnet or magnets (according to Table 4).

In QDMs: 1.6A, 1.7B,1.E nad 1.Ei:

- the US unit contains QD quadrupole and QDo bus-bar[1], QDi bus-bar, DP bus-bar pair (DPo and DPi) and corresponding corrector magnet or magnets (according to Table 4);
- the DS unit contains F1 quadrupole and F1o bus-bar[1], F1i bus-bar, F2 bus-bar pair (F2o and F2i) and corresponding corrector magnet or magnets (according to Table 4).

In QDMs: 2.123 and 2.13s:

- the US unit contains QD quadrupole with QDo and QDi bus-bars (bus bars are manufactured in conjunction with the QD coil from one piece of cable);
- the DS unit contains F2 quadrupole with F2o and F2i bus-bars (bus bars are manufactured in conjunction with the F2 coil from one piece of cable) and the steering magnet;
- caution: in cell 1, the F2 quadrupole is connected to the electrical circuit of F1 quadrupole!

The US unit and the DS Unit of regular arc section modules are presented in Fig. 5 and 6 respectively. Cold terminals of local current leads (LCL) are not shown in Fig. 5 and 6. However they are the parts of the units as well. Fig. 7 presents the cold terminal for CV (2 HTS stack version). Other variants of cold terminals of LCLs are described in section 4.6.2.

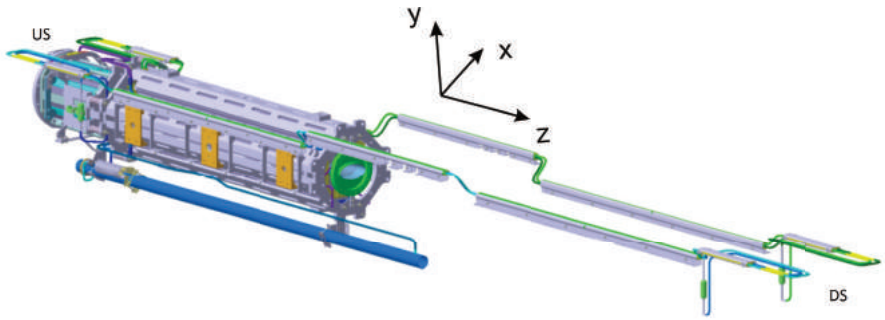


Figure 5: CAD-model of the CV-QD (VQD) unit.

[1] quadrupole are manufactured from one piece of cable in conjunction with its outer bus-bar

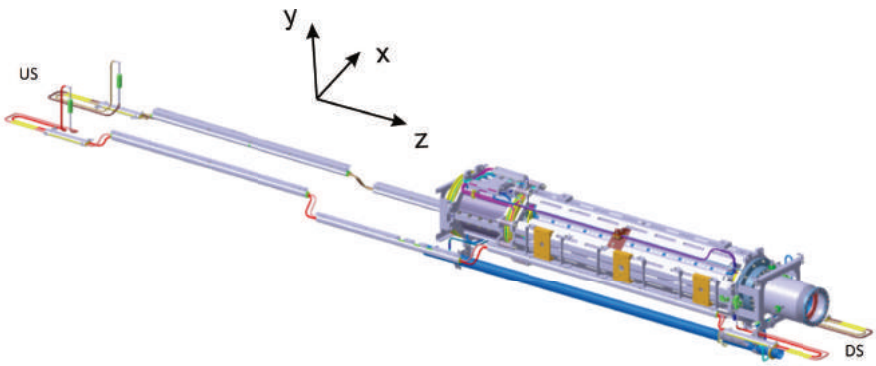


Figure 6: CAD-model of the ST-F2-BPM (SF2B) unit.

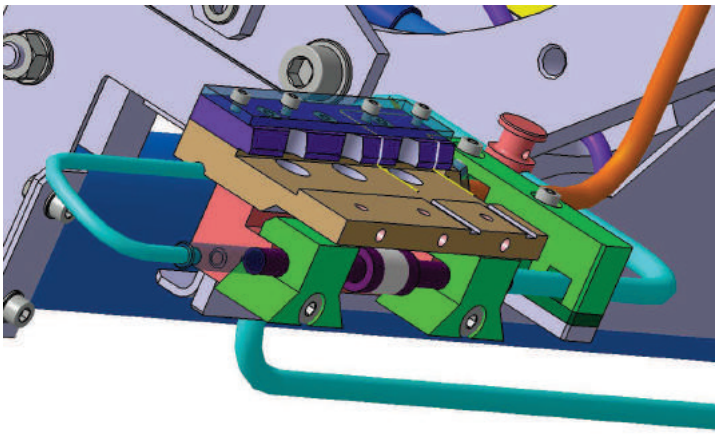


Figure 7: Cold terminal of local current leads (LCL). Two HTS stack version for chromaticity sextupole CV.

4.2 Quadrupole Magnets and Main Bus-bars

This section describes the polarity of the defocusing/focusing quadrupoles and the main bus-bars orientation. The direction of the electric current is also presented here.

4.2.1 Polarity in Quadrupole Magnets

We name here polarity the distribution of the field direction within each pole. Fig. 8 presents defocusing and focusing quadrupoles seen beam downstream (the observer sees the beam coming towards him). Fig. 8 also shows that the defocusing quadrupole will have its connection side (CS) located beam upstream (US). For the focusing quadrupole, it is the opposite: CS = DS.

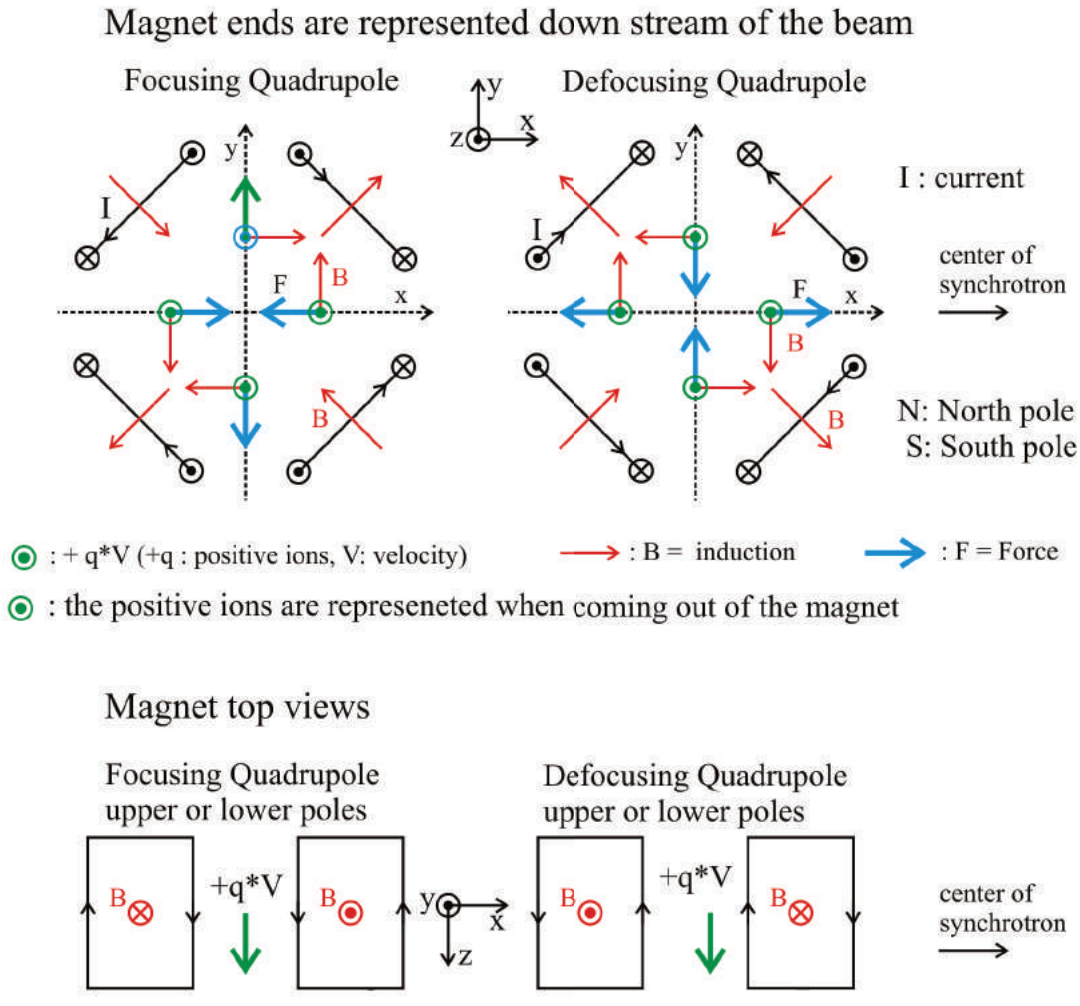


Figure 8: Main quadrupole polarities (courtesy of E. Floch).

Fig. 9 presents the current direction and the location of coil terminations for defocusing and focusing quadrupoles. Quadrupole magnets are treated in detail in [9].

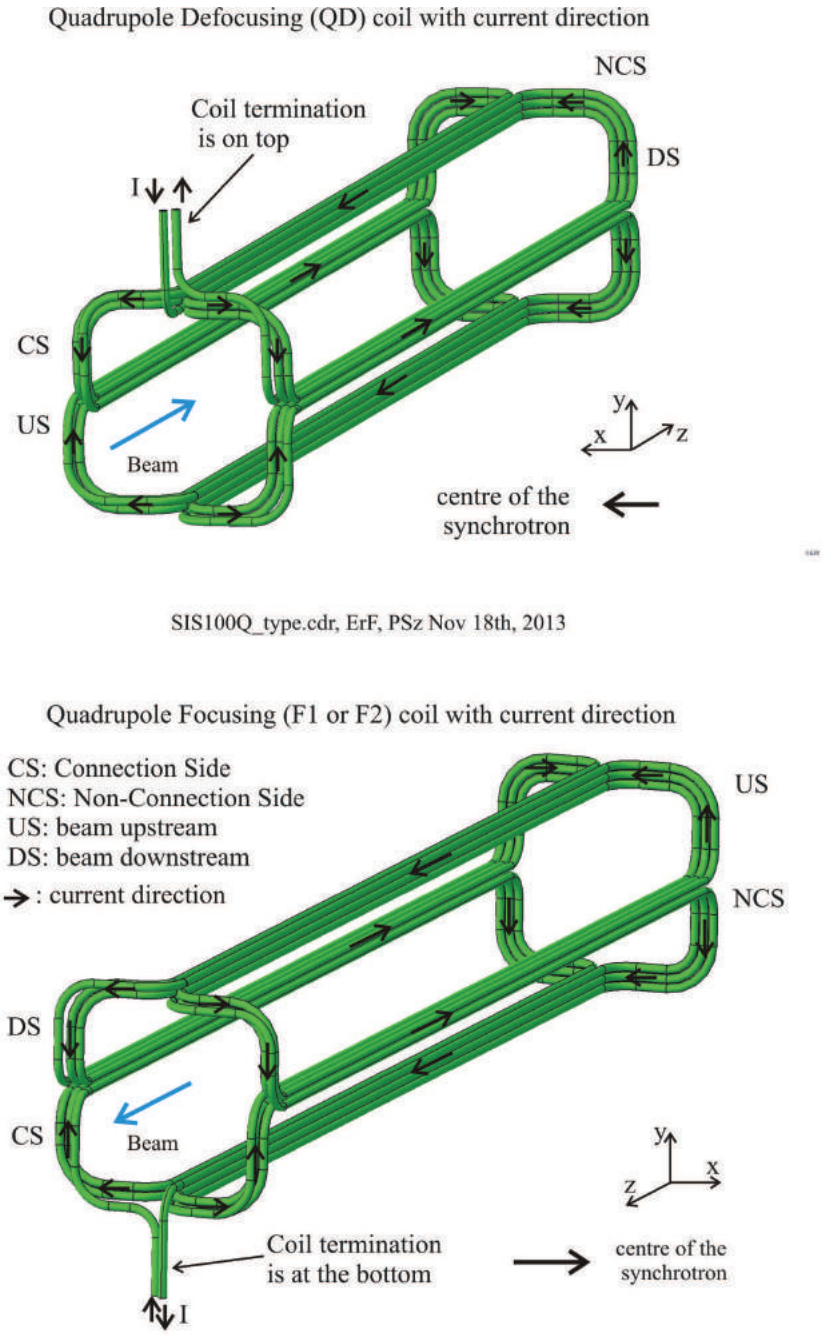


Figure 9: Current directions in quadrupole coils.

4.2.2 Main Bus-bars

The main bus-bars are the bus-bars dedicated for the dipole circuit (DPi and DPo), the quadrupole defocusing circuit (QDi and QDo), the quadrupole focusing type 1 circuit (F1i and F1o) and the quadrupole focusing type 2 circuit (F2i and F2o). Abbreviations ”i” and ”o” state for inner and outer respectively. The ”inner” bus-bar is always closer to the center of the synchrotron than the ”outer” bus-bar. The bus-bar system in of the US unit (regular arc section example) is presented in Fig. 10. The QDo bus-bar and the QD coil are made as a one component from one cable length (no superconducting joint between the QD coil and the QDo bus-bar). The bus-bar system of the DS unit (regular arc section with F2 coil example) is presented in Fig. 11. The outer bus-bar and the coil of the focusing quadrupole are made as a one component from one cable length (no superconducting joint between the coil of the focusing quadrupole and the outer bus-bar).

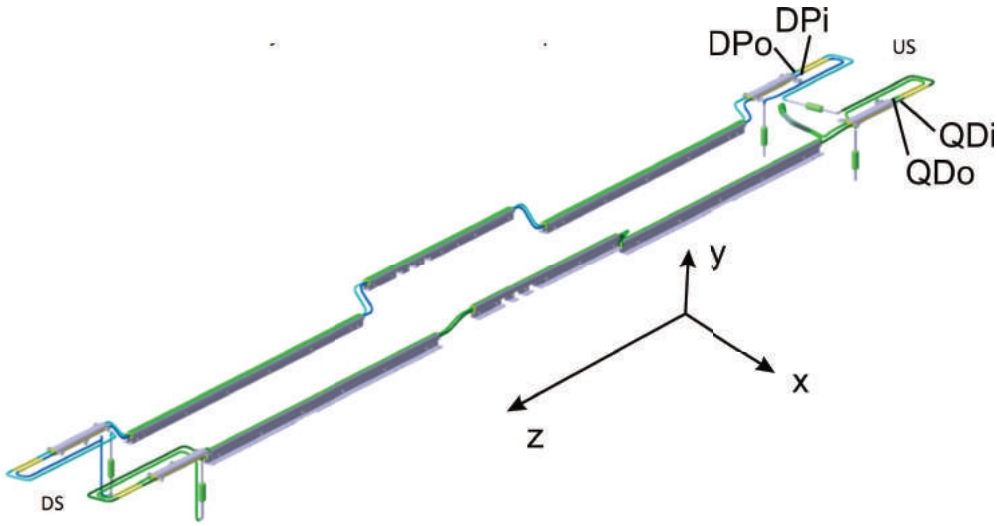


Figure 10: Model of the bus-bar system of the US unit of any regular arc section modules (the QD coil is not shown).

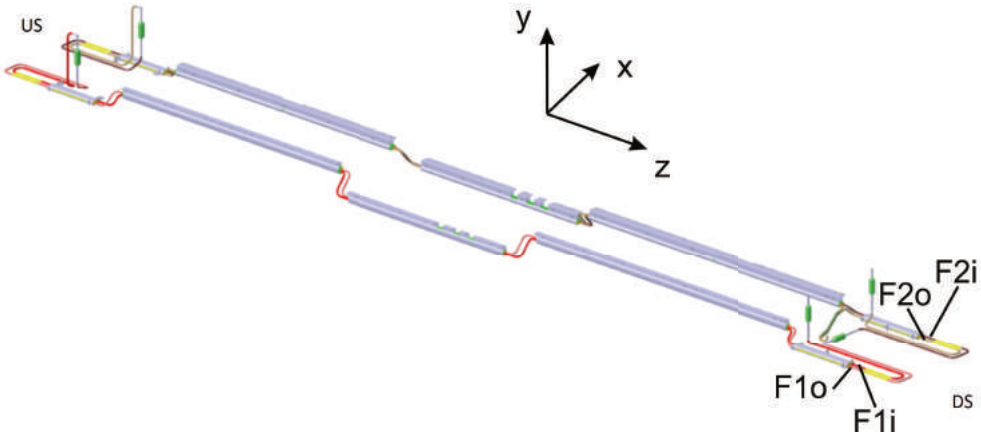


Figure 11: Model of the bus-bar system of the DS unit of regular arc section modules with F2 quadrupole (the F2 coil is not shown).

Fig. 12 presents the colors and current directions to be used in electrical diagrams when describing bus-bars.

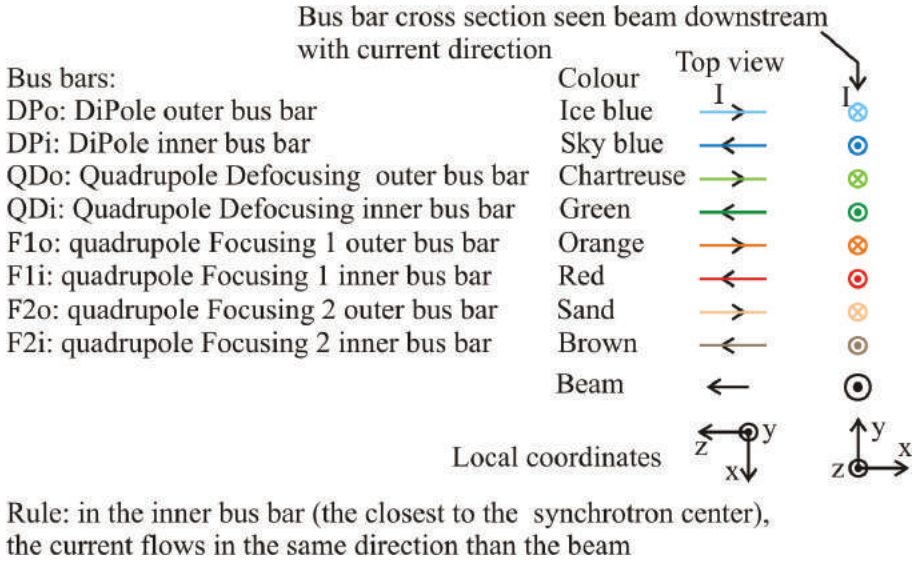


Figure 12: Colors and current directions to be used in electrical diagrams when describing bus-bars (courtesy of E. Floch).

Fig. 13 presents the current direction in each of the 8 bus-bars (example of regular arc section modules with F2 coil). The current direction in all ”inner” bus-bars agrees with the beam direction while the current direction in all ”outer” bus-bars is opposite to the beam direction. Quadrupoles are always fed with current that comes from the ”outer” bus-bar.

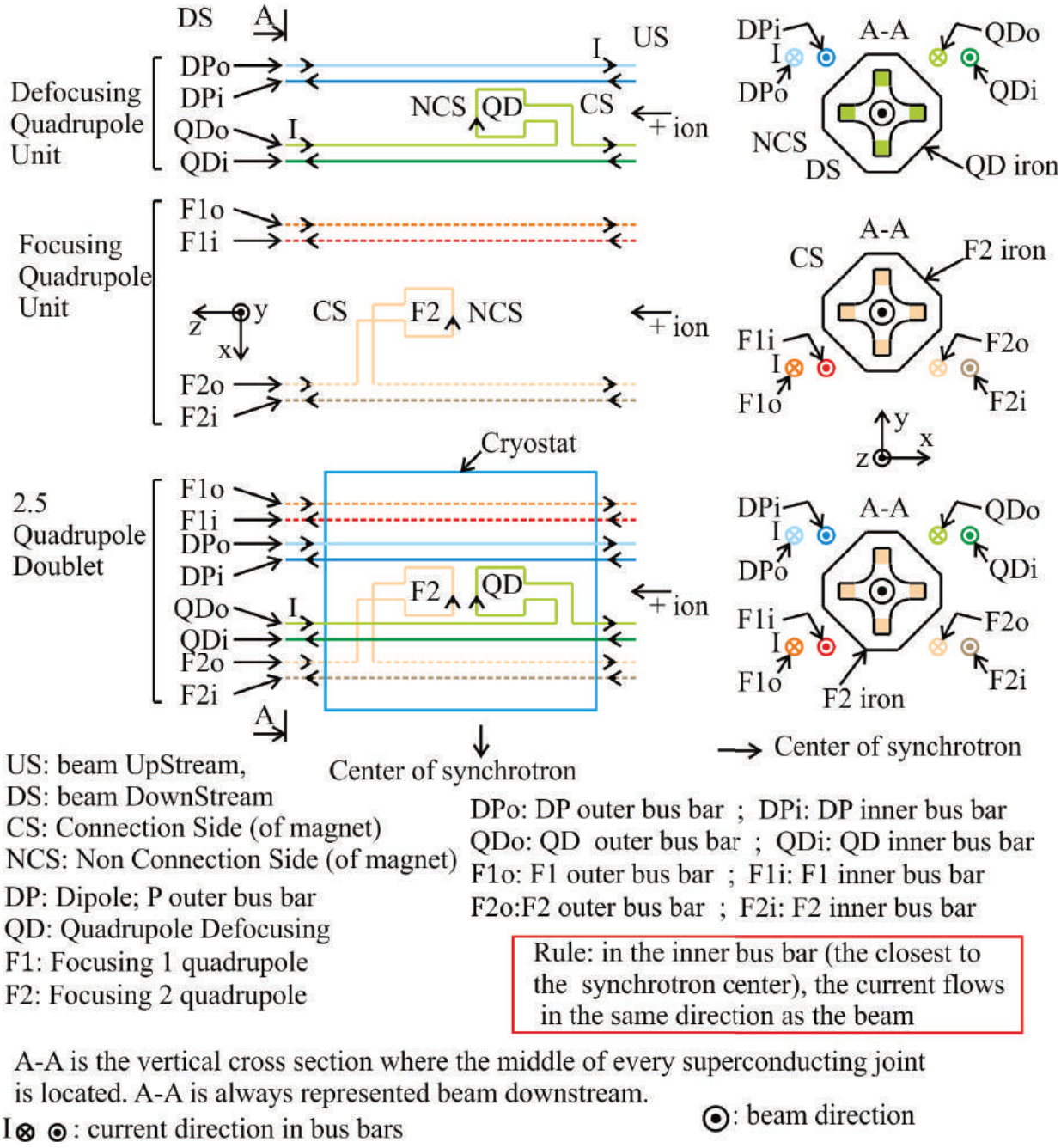


Figure 13: Bus-bars with current directions for regular arc section modules with F2 coil (courtesy of E. Floch).

Fig. 14 and 15 present the 3D bus-bar arrangement in US and DS units of QDM 2.5 respectively. Similar bus-bar 3D bus-bar arrangement is applied to all QDMs except straight sections.

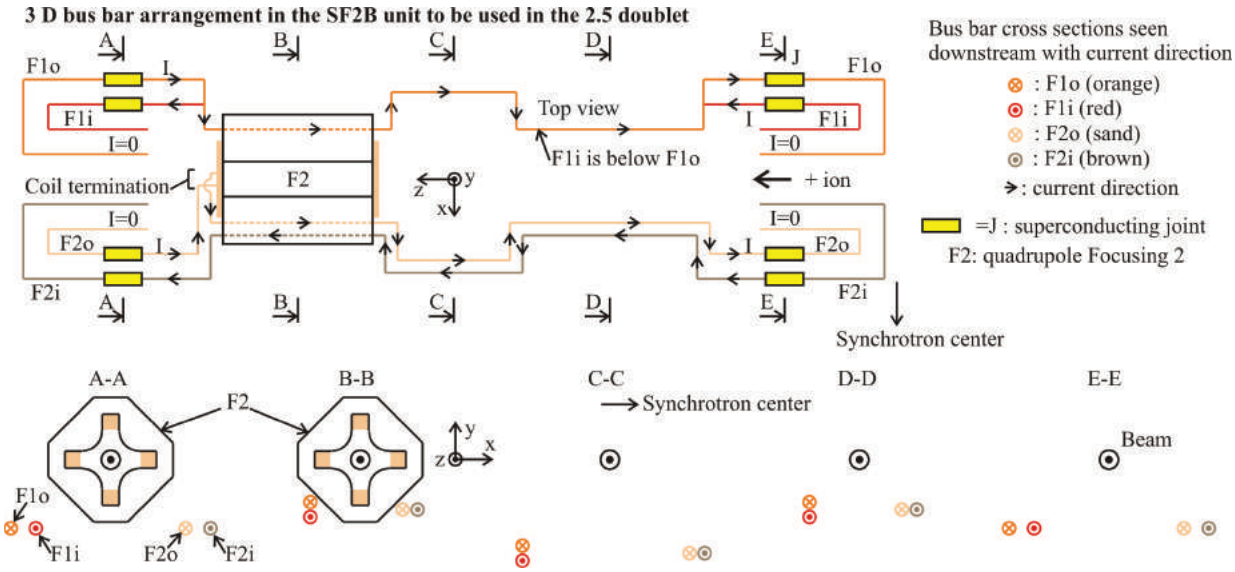


Figure 14: 3D bus-bar arrangement in the DS unit of QDM 2.5 (courtesy of E. Floch).

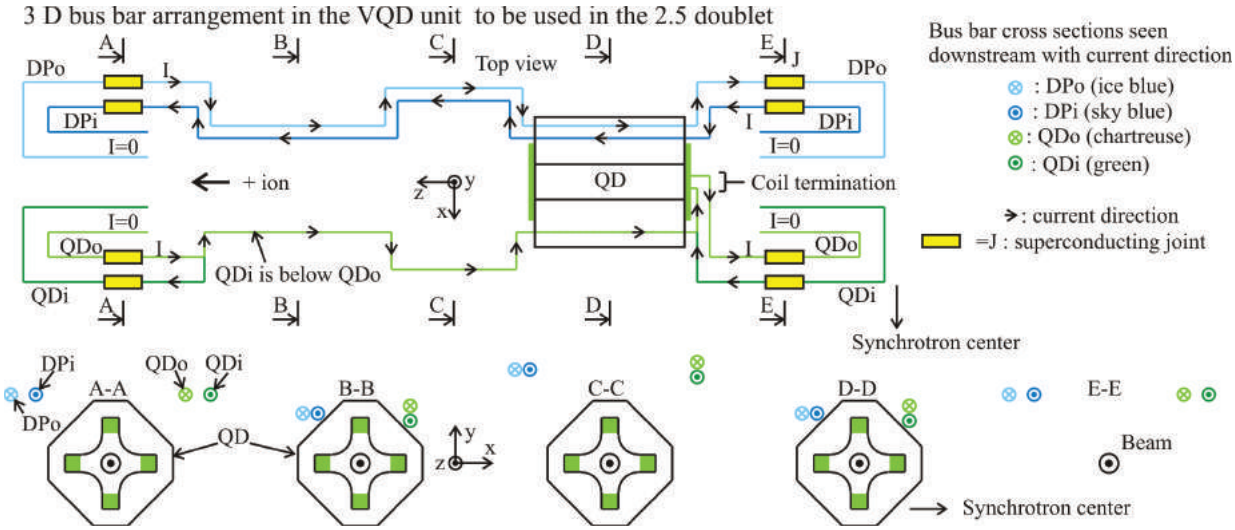


Figure 15: 3D bus-bar arrangement in the US unit of QDM 2.5 (courtesy of E. Floch).

Fig. 16 presents the 3D bus-bar arrangement for QDM 2.5. Similar bus-bar 3D bus-bar arrangement is applied to all QDMs except straight sections. In the straight sections, quadrupole bus-bars are routed in a direct way towards the end-cap where the superconducting joints are done. There are no DP and F1 bus-bars in the QDMs 2.123 and 2.13s (straight sections).

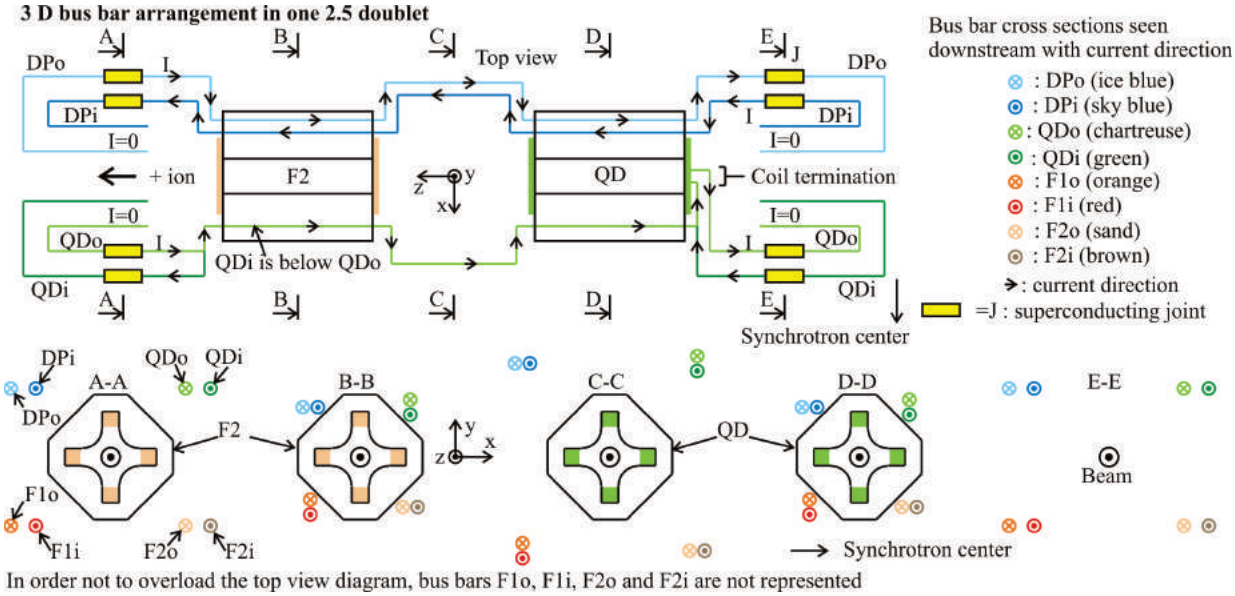


Figure 16: 3D bus-bar arrangement in the 2.5 quadrupole doublet (courtesy of E. Floch).

Fig. 17 shows that the 4 bus-bar pair centres always form a rectangle. The distance between 2 bus-bar centers from the same pair is d_p=9 mm everywhere except in the last part where the superconducting joint is made (d_p=25 mm). In order to reduce the cross-talk between bus-bar pairs, QD and F1 bus-bar pairs are oriented vertically while DP and F2 bus-bar pairs are oriented horizontally. When the bus-bars are arranged vertically, the outer bus-bar is always on top of the inner one. At joint sections all bus-bars have horizontal orientation.

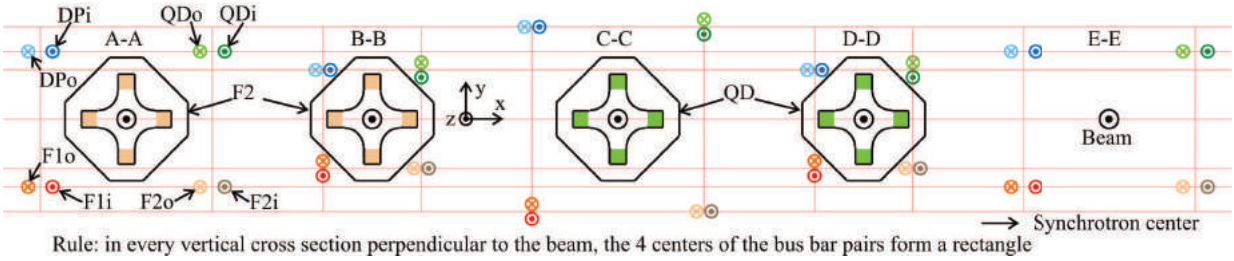


Figure 17: Cross sections in the 2.5 quadrupole doublet (courtesy of E. Floch).

4.3 Corrector Magnets and Their Bus-bars

The corrector magnets will use a special nuclotron cable with insulated strands (28 insulated strands, see Fig. 18). In the chromaticity sextupole, steering magnet (vertical and horizontal coil) and multipole corrector (quadrupole coil, sextupole coil, and octupole coil), one strand out of 28 coil strands is reserved for quench detection.

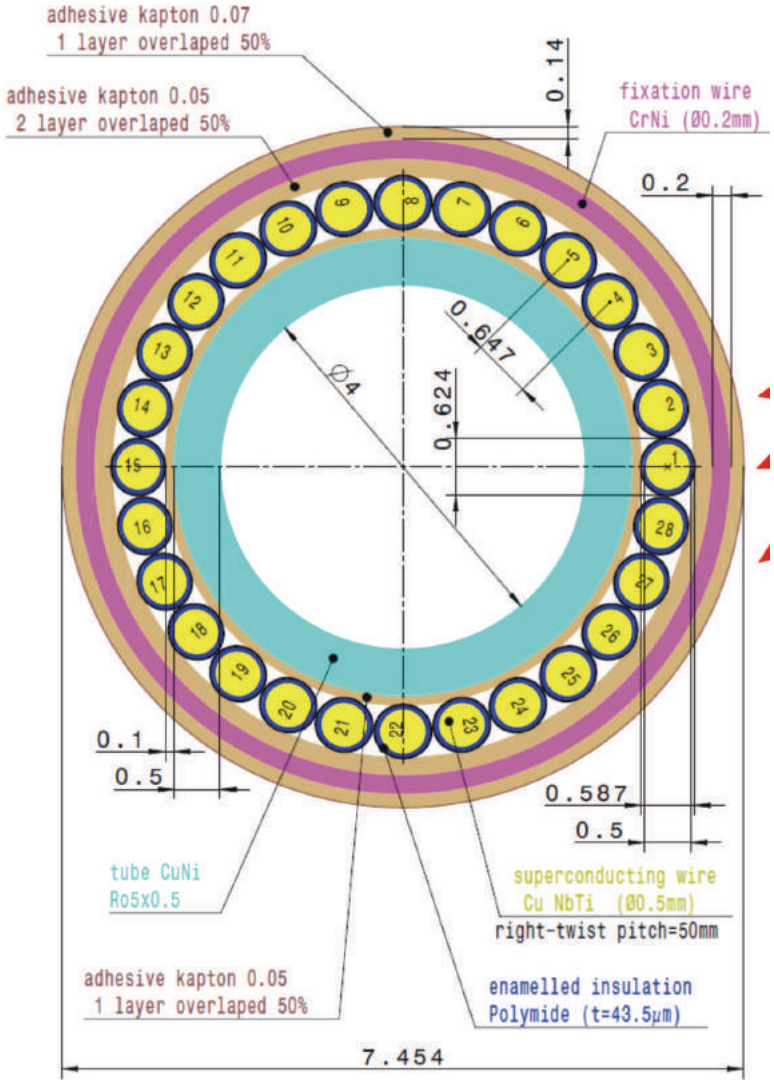
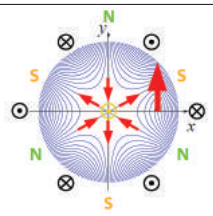
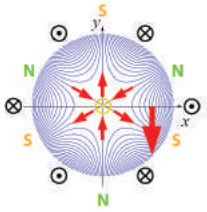
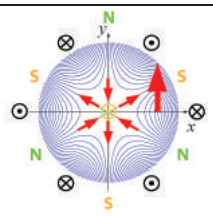
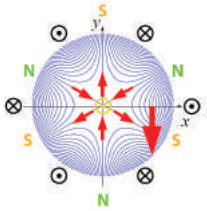
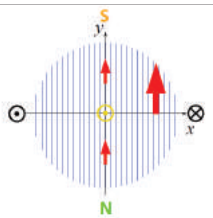
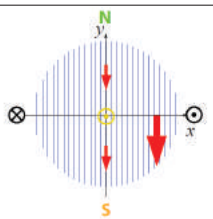
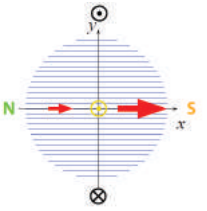
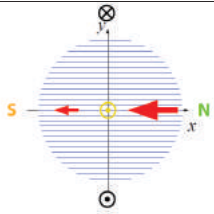
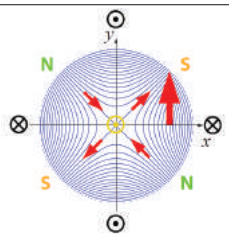
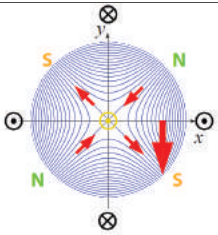
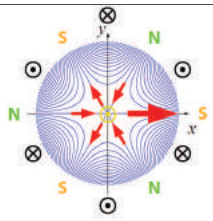
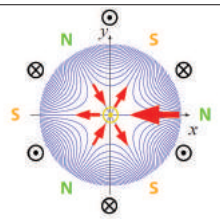
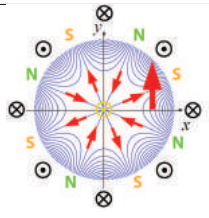
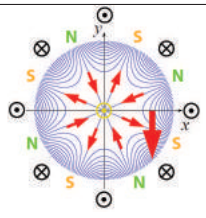


Figure 18: Corrector cable with insulated strands.

4.3.1 Polarity in Corrector Magnets

In order to properly connect the current leads of correctors to corresponding power supplies, Table 5 defines the so-called positive and negative polarity.

Table 5: Definition of the so-called positive and negative polarity for correctors within the quadrupole doublet modules (Courtesy of K. Sugita)

Magnet or coil	Positive polarity	Negative palarity
Chromaticity sextupole (CH)		
Chromaticity sextupole (CV)		
Horizontal steerer (SH)		
Vertical steerer (SV)		
Multipole corr. quadrupole (MQ)		
Multipole corr. sextupole (MS)		
Multipole corr. octupole (MO)		

The chromaticity sextupole CV will be powered for most of the time in its negative polarity while the other chromaticity sextupole CH will be powered for most of the time in its positive polarity The steering magnet coils will be powered for most of the time in their positive polarity. The current directions in these magnets are presented in Fig. 19, 20 and 22. In the positive polarity, the current flows from the positive current lead to the negative current lead. Current leads are installed on the upper part of the service port.

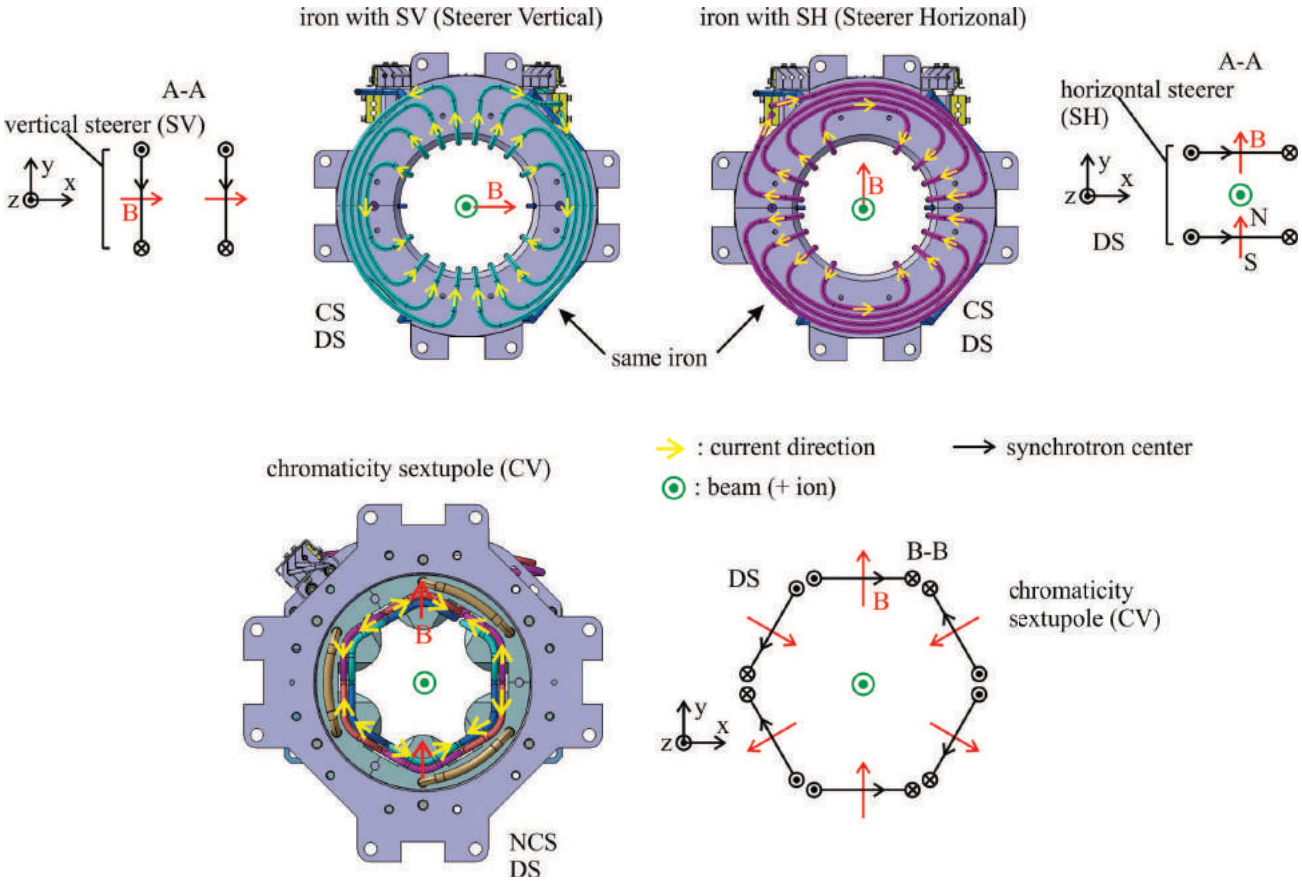


Figure 19: Current direction in the steering magnet powered in ”positive polarity” and in the chromaticity sextupole (CV) powered in ”negative polarity”.

Fig. 20, 21 and 22 show the current direction in the chromaticity sextupole veritcal (CV), chromaticity sextupole horizontal (CH) and steering magnet (ST), respectively.

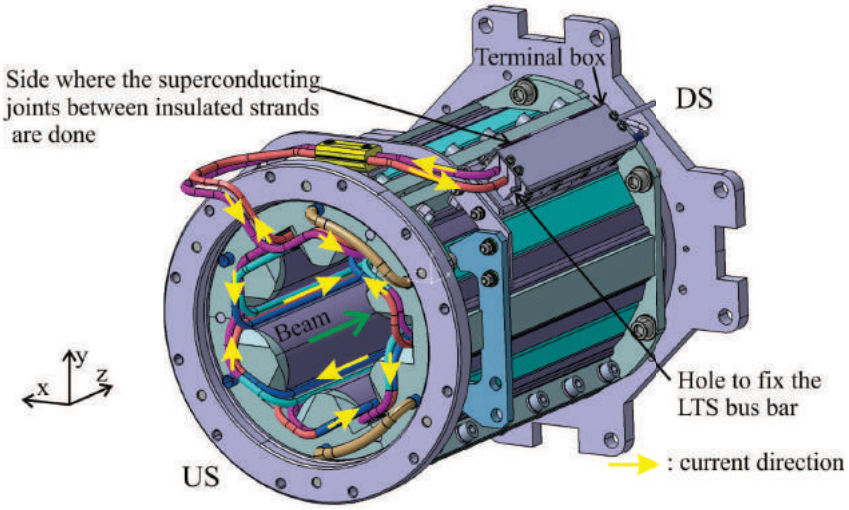


Figure 20: Current direction in the chromaticity sextupole CV (negative polarity).

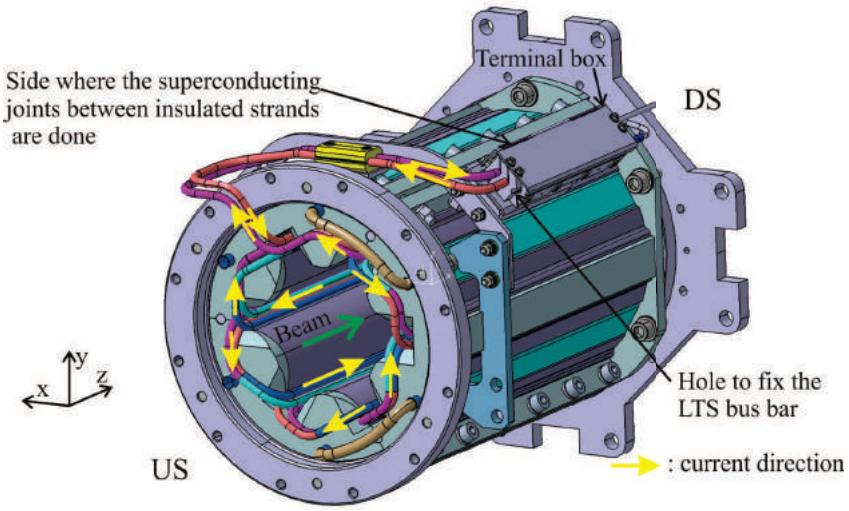


Figure 21: Current direction in the chromaticity sextupole CH (positive polarity).

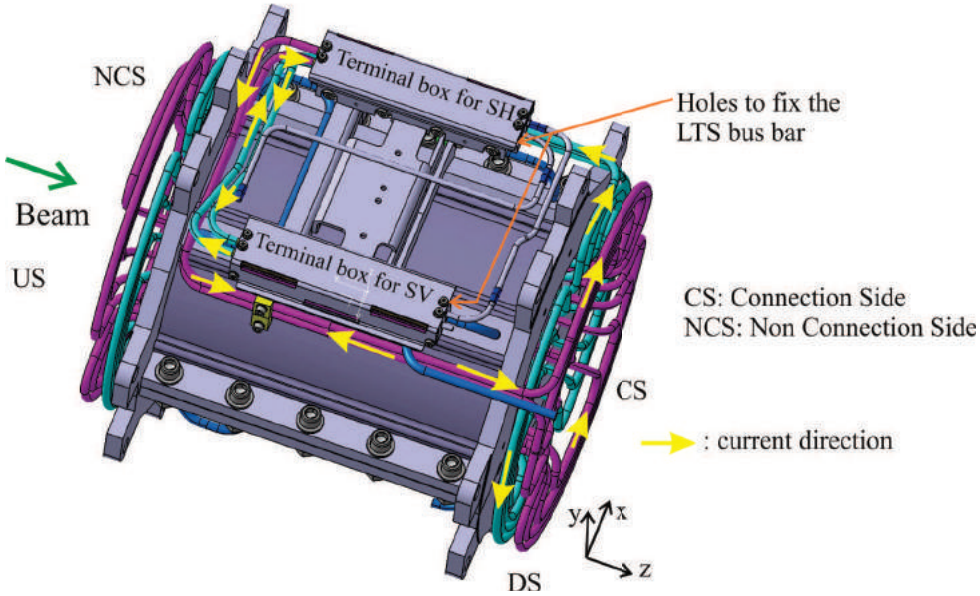


Figure 22: Current direction in the steering magnet ST (positive polarity).

Fig. 23 presents the 3D model of the multipole corrector. The multipole corrector consist of three independent coils that shares the same iron yoke:

- quadrupole coil (MQ),
- sextupole coil (MS),
- octupole coil (MO).

The coil interconnections and bus-bar connections are done in the terminal box. Each coil has own terminal box (TMQ for MQ, TMS for MS and TMO for MO).

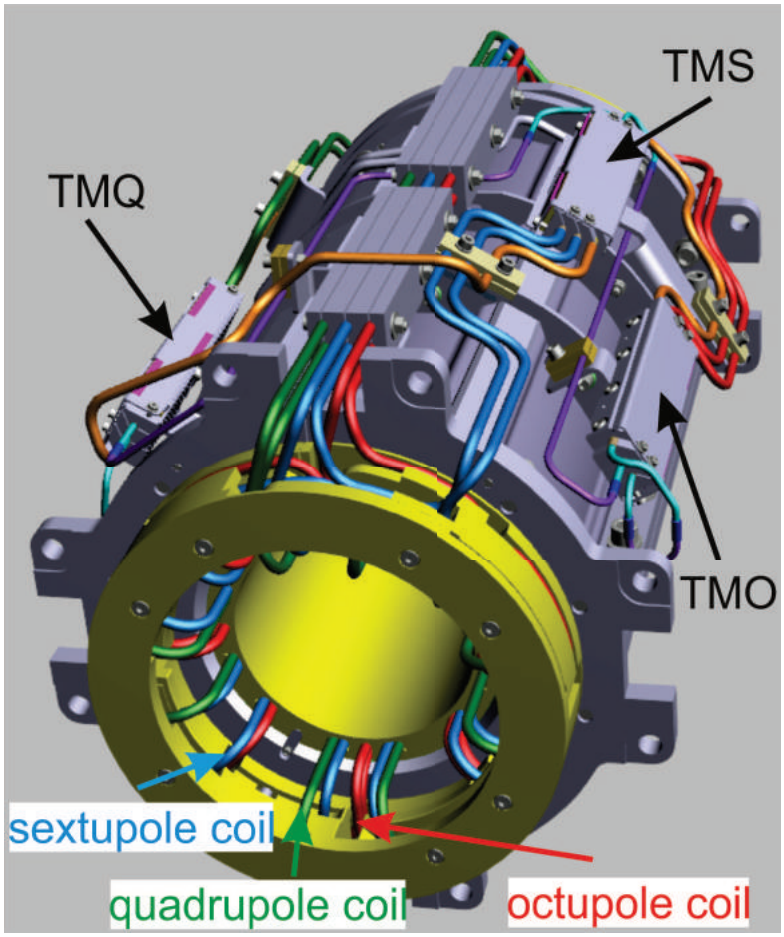


Figure 23: 3D model of the multipole corrector.

4.3.2 Bus-bars for Correctors

In QDMs, corrector coils are connected to their current leads via a LTS (Low Temperature Superconductor) bus-bar. This bus-bar also uses the corrector cable. Fig. 24 shows (as an example) the horizontal and vertical steerers, their common LTS bus-bar (28-strand cable) and their 4 current leads. Each corrector coil has a terminal box (in case of ST there are two terminal boxes: TSV and TSV) where its strands are connected in series and which receives the LTS bus-bar. Each current lead is made of a vertical copper part (300 to 70K) and one horizontal HTS (High Temperature Superconductor) stack (70 to 4K). Both copper and HTS are conduction cooled. The cold terminal of local current leads is a part of the unit.

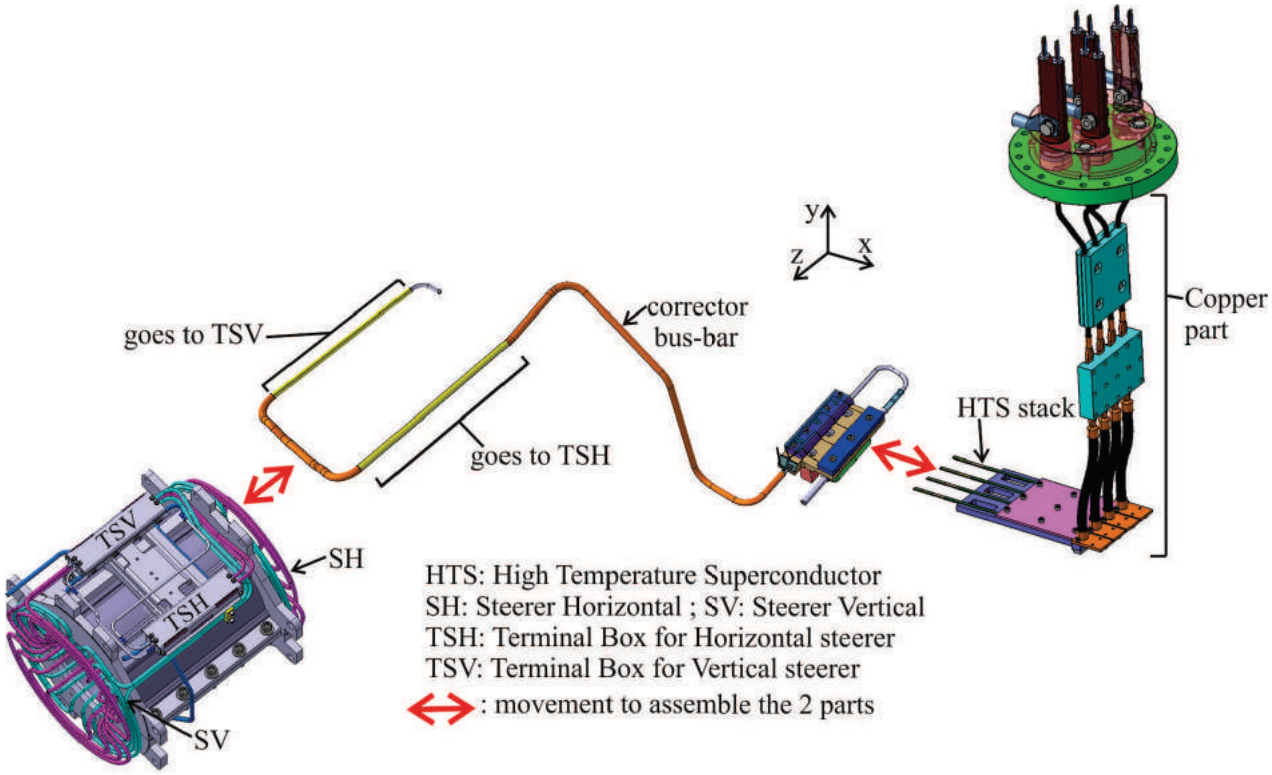


Figure 24: Horizontal and vertical steerers (SH and SV) with their bus-bar and current leads.

For connections of the corrector bus-bar in the terminal boxes see electrical drawings:

- GSI-SIS100-QDM-1.6A-001 – GSI-SIS100-QDM-1.6A-003;
- GSI-SIS100-QDM-1.7B-001 – GSI-SIS100-QDM-1.7B-003;
- GSI-SIS100-QDM-1.E-001 – GSI-SIS100-QDM-1.E-005;
- GSI-SIS100-QDM-1.Ei-001 – GSI-SIS100-QDM-1.Ei-008;
- GSI-SIS100-QDM-2.4-001 – GSI-SIS100-QDM-2.4-005;
- GSI-SIS100-QDM-2.4x-001 – GSI-SIS100-QDM-2.4x-008;
- GSI-SIS100-QDM-2.5-001 – GSI-SIS100-QDM-2.5-003;
- GSI-SIS100-QDM-2.8C-001 – GSI-SIS100-QDM-2.8C-003;
- GSI-SIS100-QDM-2.9D-001 – GSI-SIS100-QDM-2.9D-003;
- GSI-SIS100-QDM-2.123-001 – GSI-SIS100-QDM-2.123-004.

4.4 Low Current Quadrupoles (Injection/Extraction Quadrupoles) and Their Bus-bars

The low current quadrupoles (LQ) will use a special nuclotron cable with insulated strands (21 insulated strands, see Fig. 25). One strand out of 21 coil strands is reserved for quench detection. Fig. 26 shows a 3D model of LQ. LQ is fed with current via 2 pairs of LCL (same design as for corrector magnets). LCL pairs are connected in parallel. The connection between LCLs and the magnet is done via a bus-bar made from the LQ coil cable (21-strand cable). The bus-bar is connected to the magnet in the terminal box (TLQX or TLQY). For connections in the terminal box see electrical drawings:

- GSI-SIS100-QDM-1.Ei-001 – GSI-SIS100-QDM-1.Ei-008;
- GSI-SIS100-QDM-2.4x-001 – GSI-SIS100-QDM-2.4x-008.

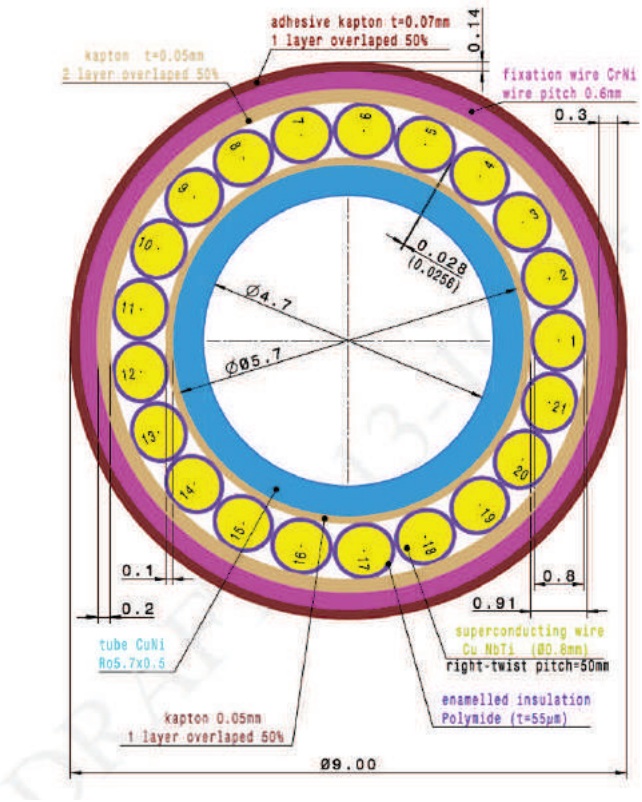


Figure 25: Corrector cable with insulated strands dedicated for LQ.

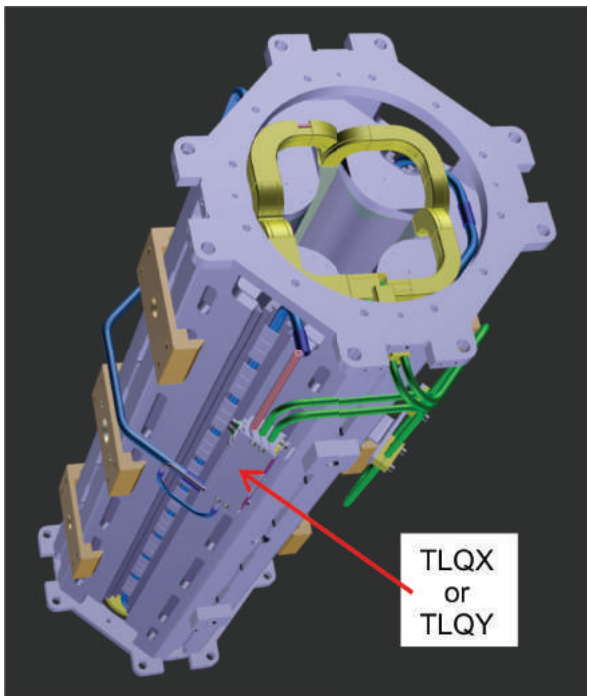


Figure 26: Low current quadrupole for the injection/extraction system.

4.5 Gamma-t Jump Quadrupole

The gamma-t jump quadrupole (QJ) is a normal conducting magnet that will be operated at cold conditions and located inside QDM 2.9D. QJ will be fed with current via a copper multi-wire cable. Fig. 27 shows a 3D model of QJ. Since QJ is a normal conducting magnet, no voltage taps are foreseen for this magnet and its connection interface. For connections of the magnet see electrical drawings GSI-SIS100-QDM-2.9D-001 – GSI-SIS100-QDM-2.9D-003.

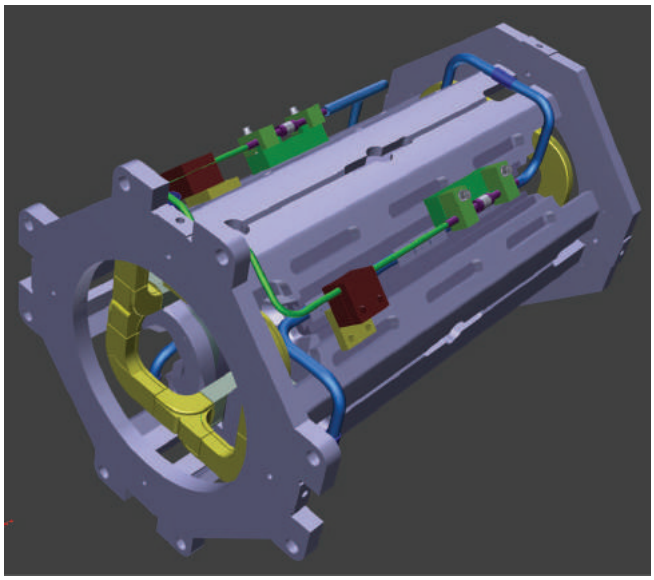


Figure 27: Gamma-t Jump Quadrupole.

4.6 Voltage Taps in Quadrupole Doublet Modules

All superconducting machines need to be protected against quench. A fast and reliable quench detection is the most essential part of the quench protection system. In superconducting magnets of SIS100, the quench is detected by surveying the voltage at defined points. Therefore voltage taps need to be installed in each point of interest. Table 6 gives the voltage tap nomenclature for quadrupoles, main bus-bars, correctors (including LCLs and corrector bus-bars), low current quadrupole (including LCLs and LQ bus-bars).

Table 6: Voltage tap nomenclature for magnets and bus-bars in SIS100 QDMs

Object	first	last	n° of Vtaps	socket name
QD coil	VQD1	VQD6	6	SQD
F1 coil	VF11	VF16	6	SF1
F2 coil	VF21	VF26	6	SF2
bus-bars	VBQ1	VBQ8	8	SBQ
horizontal steerer (SH)	VH01	VH18	18	SSH
vertical steerer (SV)	VV01	VV18	18	SSV
chromaticity sextupole (CV or CH)	VC01	VC18	18	SCS
multipole corrector: quadrupole coil	VQ01	VQ18	18	SMQ
multipole corrector: sextupole coil	VS01	VS18	18	SMS
multipole corrector: octupole coil	VO01	VO18	18	SMO
low current quadrupole (injection/extraction)	VX01 or VY01	VX30 or VY30	30	SX1, SX2 or SY1, SY2

4.6.1 Voltage Taps for Quadrupoles

A voltage tap shall be soldered to the superconducting cable in the way that a very good electrical contact is achieved. The soldering shall be reliable and shall withstand the aging process. One shall use Sn96Ag4 soldering and high quality, non-corrosive soldering flux that is suitable for cryogenic temperature. A use of a copper clamp with a pinning hole is recommended. The contractor shall propose the solution for installing the voltage taps (fixation structure). This solution needs to be accepted by the company. After the soldering process, the soldering area shall be insulated with adhesive polyimide tape which will also mechanically fix the voltage tap wire. Fig. 28 and 29 show the exact location of voltage taps for a F2 unit and QD unit respectively. A F1 unit is just a ”mirrored” version of F2 unit. The order of voltage taps dedicated for the quadrupole coil always follow the current. Votage taps 1&2 are installed at the current input, 3&4 at the middle of the coil and 5&6 at the current output.

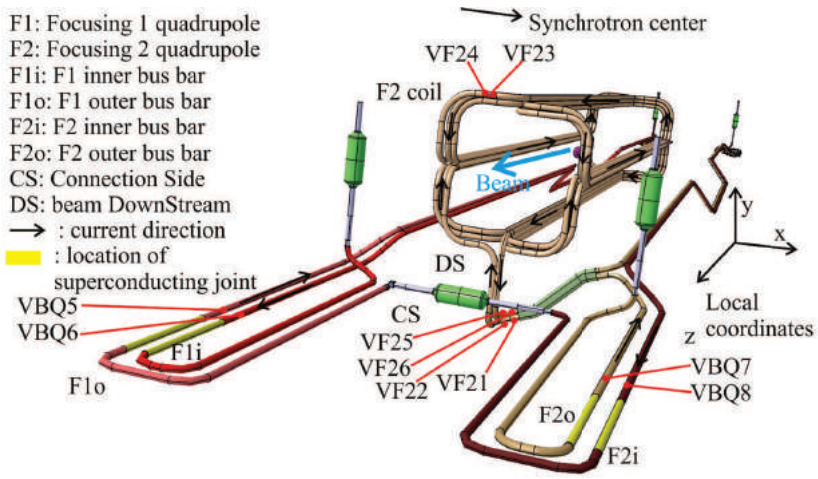


Figure 28: Precise location of the voltage taps in a F2 unit.

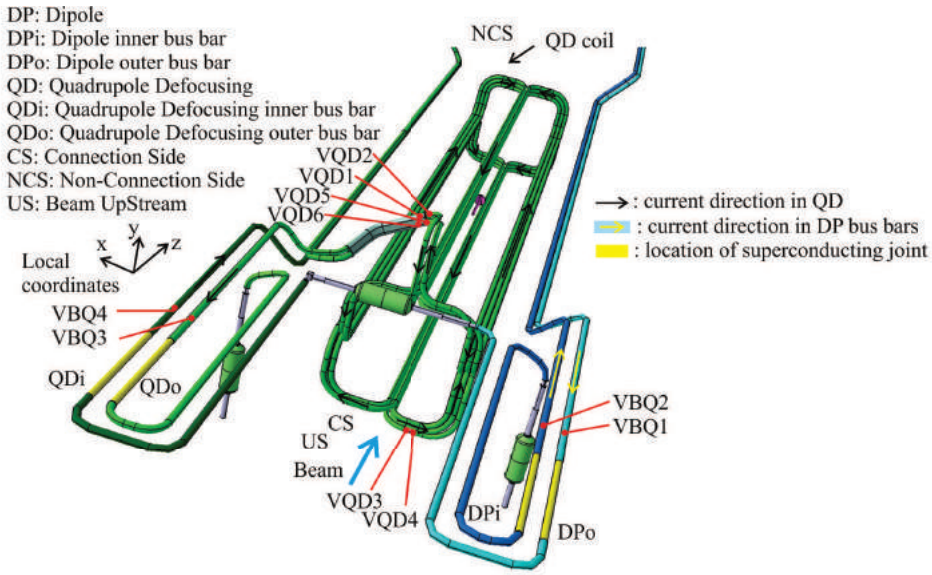


Figure 29: Precise location of the voltage taps in a QD unit.

The detailed schemes of quadrupole circuits are presented in electrical drawings:

- GSI-SIS100-QDM-1.6A-001 – GSI-SIS100-QDM-1.6A-003;
- GSI-SIS100-QDM-1.7B-001 – GSI-SIS100-QDM-1.7B-003;
- GSI-SIS100-QDM-1.E-001 – GSI-SIS100-QDM-1.E-005;
- GSI-SIS100-QDM-1.Ei-001 – GSI-SIS100-QDM-1.Ei-008;
- GSI-SIS100-QDM-2.4-001 – GSI-SIS100-QDM-2.4-005;
- GSI-SIS100-QDM-2.4x-001 – GSI-SIS100-QDM-2.4x-008;
- GSI-SIS100-QDM-2.5-001 – GSI-SIS100-QDM-2.5-003;
- GSI-SIS100-QDM-2.8C-001 – GSI-SIS100-QDM-2.8C-003;
- GSI-SIS100-QDM-2.9D-001 – GSI-SIS100-QDM-2.9D-003;
- GSI-SIS100-QDM-2.123-001 – GSI-SIS100-QDM-2.123-004.

4.6.2 Voltage Taps for Correctors

The local current leads (one pair per coil), the corrector bus-bar and the corrector coil are electrically connected to each other and they shall be treated as a one electric system with common quench detection. Fig. 30 presents the number and location of voltage taps that are connected to each corrector coil (via corrector bus-bar) and associated HTS current leads. The voltage taps are always doubled (i.e: voltage taps 1 and 2 are connected at the same level on the copper part of the positive current lead). The voltage taps shall be soldered in the way that a very good electrical contact is achieved. The soldering shall be reliable and shall withstand the aging process. One shall use Sn96Ag4 soldering and high quality, non-corrosive soldering flux that is suitable for cryogenic temperature. A use of a copper clamp with a pinning hole is recommended. The contractor shall propose the solution for installing the voltage taps (fixation structure). This solution needs to be accepted by the company. After the soldering process, the soldering area shall be insulated with adhesive polyimide tape which will also mechanically fix the voltage tap wire. Voltage taps 7-8 and 15-18 are soldered to the superconducting strands that are not mechanically stabilized. The contractor shall propose a fixation method for these strands. The fixation method needs to be accepted by the company.

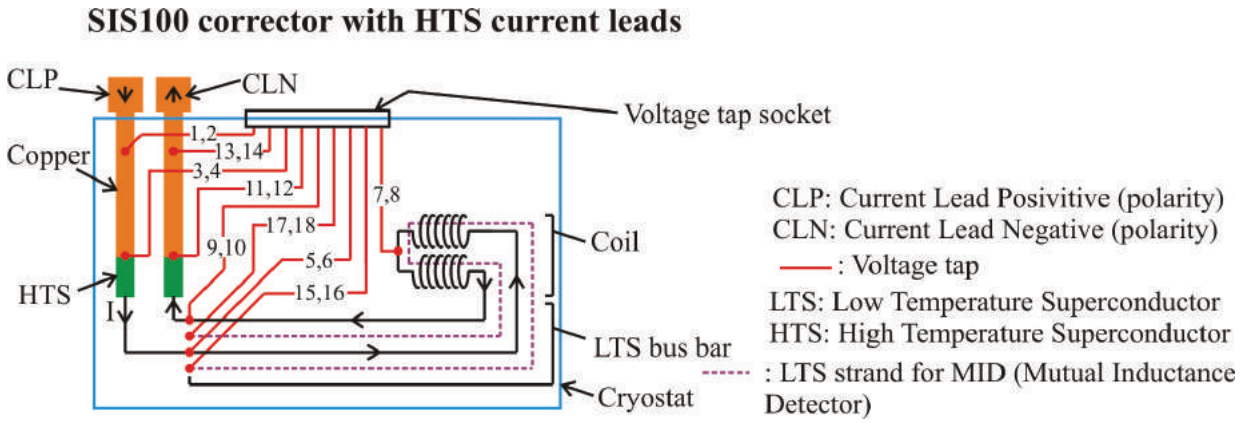


Figure 30: Voltage tap location for a single coil of a corrector magnet (courtesy of E. Floch).

In the CV-QD units, the chromaticity sextupole has a dedicated bus-bar (28-strand cable) that connects the CV coil to the cold terminal of LCL pair. Fig. 31 shows this connection and it also shows the precise location of voltage taps. Two LTS strands that carry the current are soldered to the two HTS stacks. The other 6 LTS strands are used as a voltage tap wire and bring the electrical potential from the points of interests (located in the terminal box TCV).

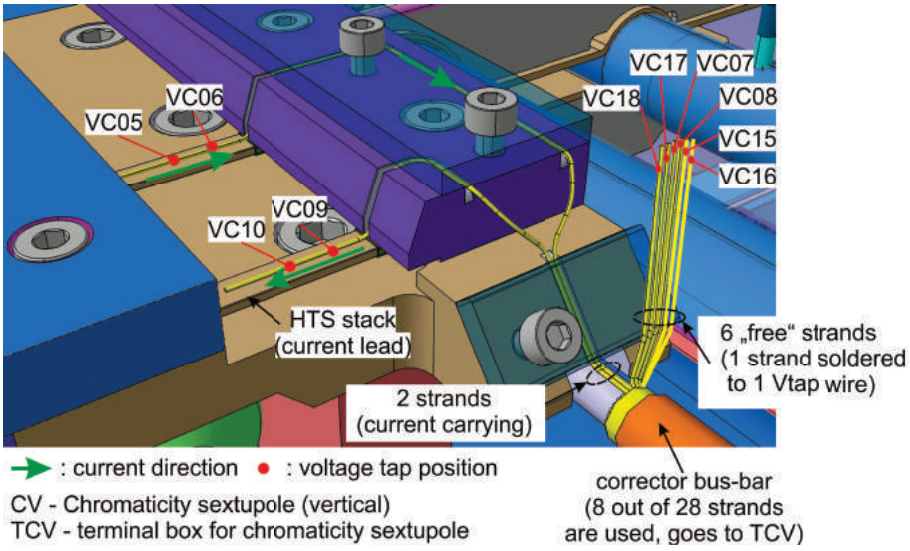


Figure 31: Cold terminal of local current leads. Precise location of voltage taps dedicated for quench detection of the chromaticity sextupole.

Fig. 32 and 33 show voltage taps that are soldered to the local current leads of chromaticity sextupole (1 pair of current leads).

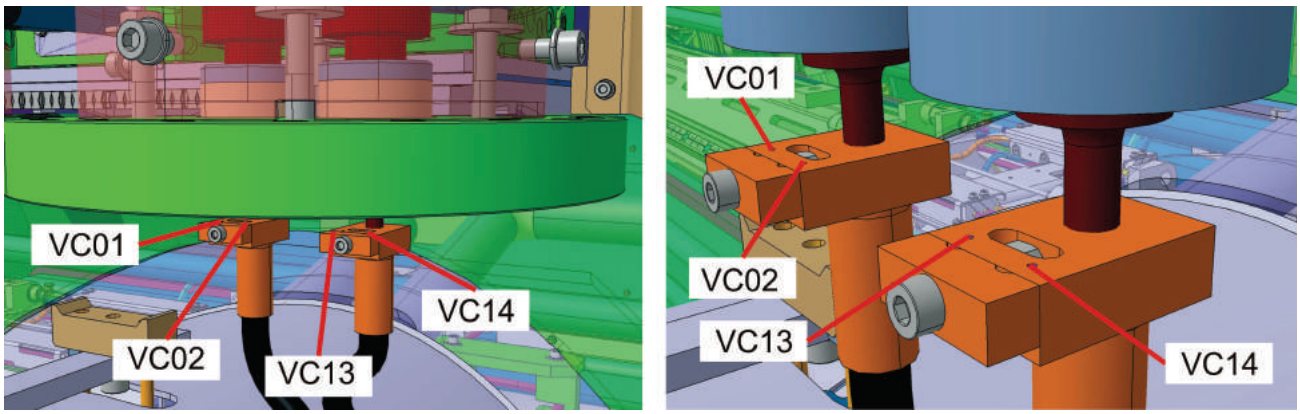


Figure 32: Warm terminals of local current leads. Precise location of voltage taps dedicated for quench detection of the chromaticity sextupole.

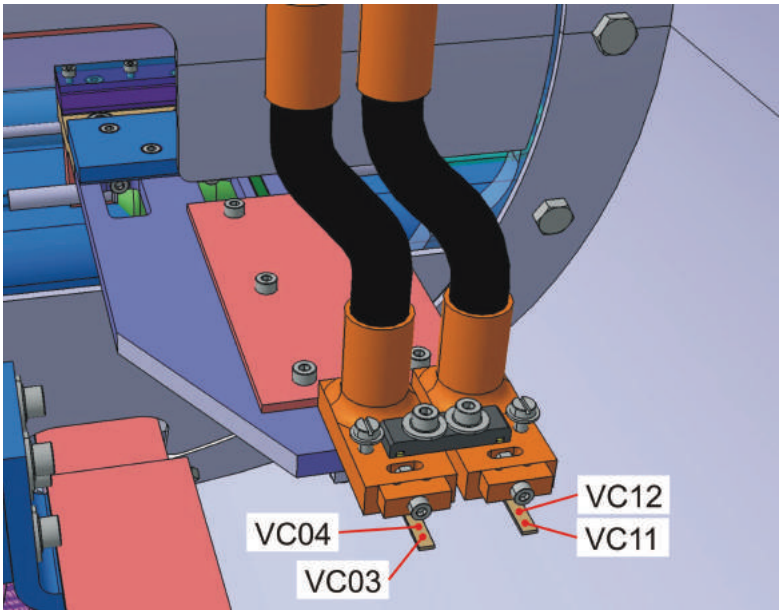


Figure 33: Local current leads: connections between Cu parts and HTS stacks. Precise location of voltage taps dedicated for quench detection of the chromaticity sextupole.

In the ST-F1, ST-F2 and ST-F2-QJ units, the steering magnet has a dedicated bus-bar (28-strand cable) that connects the SV and SH coils to the cold terminal of LCL pairs (2 pairs). Fig. 34 shows this connection and it also shows the precise location of voltage taps. Four LTS strands that carry the current are soldered to the four HTS stacks. The other 12 LTS strands are used as a voltage tap wire and bring the electrical potential from the points of interests (located in the terminal boxes TSV and TSH).

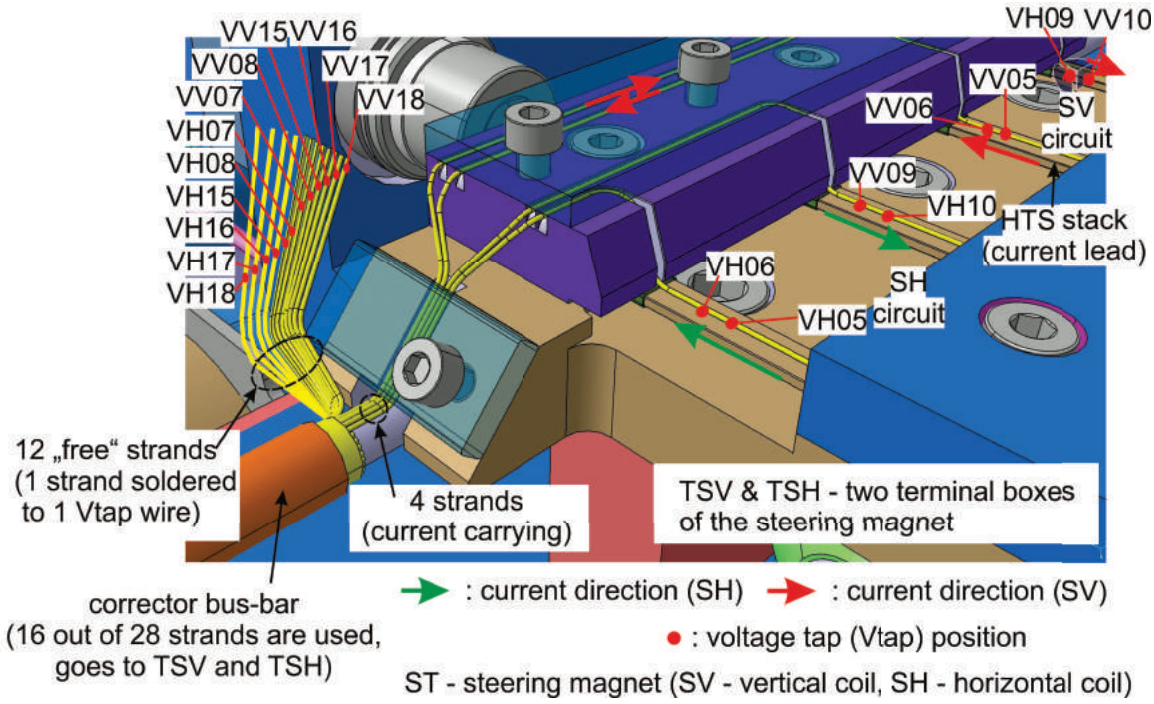


Figure 34: Cold terminal of local current leads. Precise location of voltage taps dedicated for quench detection of the steering magnet.

Fig. 35 and 36 show voltage taps that are soldered to the local current leads of steering magnet (2 pairs of current leads).

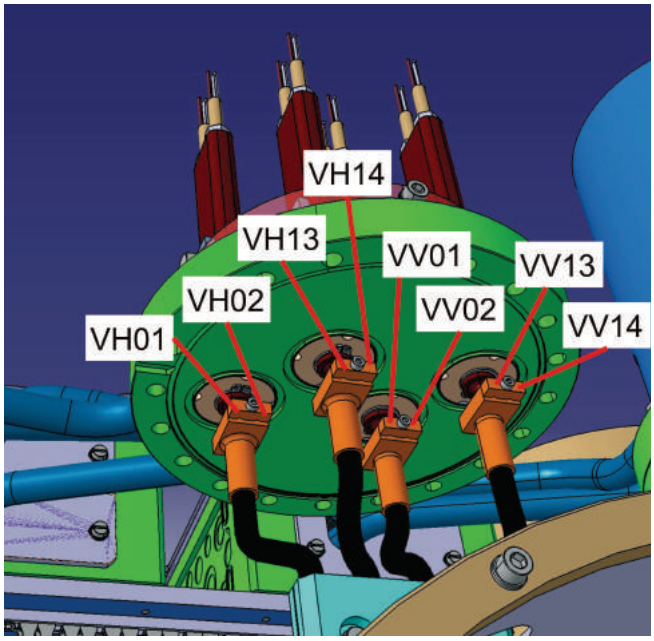


Figure 35: Warm terminals of local current leads. Precise location of voltage taps dedicated for quench detection of the steering magnet.

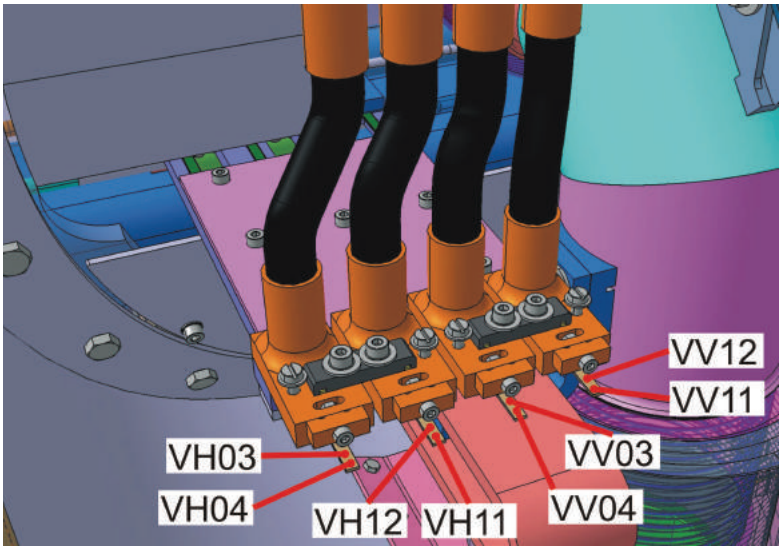


Figure 36: Local current leads: connections between Cu parts and HTS stacks. Precise location of voltage taps dedicated for quench detection of the steering magnet.

In the ST-F1-CH and ST-F2-CH units, the steering magnet and the chramaticity sextupole has a common bus-bar (28-strand cable) that connects the CH coil, and SV/SH coils to the cold terminal of LCL pairs (1 pair for CH and 2 pairs ST). Six LTS strands that carry the current are soldered to the six HTS stacks. The other 18 LTS strands are used as a voltage tap wire and bring the electrical potential from the points of interests (located in the terminal boxes TSV, TSH and TCH).

In the MC-QD unit the multipole corrector has a dedicated bus-bar (28-strand cable) that connects the MQ, MS and MO coils to the cold terminal of LCL pairs (3 pairs). Six LTS strands that carry the current are soldered to the six HTS stacks. The other 18 LTS strands are used as a voltage tap wire and bring the electrical potential from the points of interests (located in the terminal boxes TMQ, TMS and TMO).

In the ST-F2-MC unit, both the steering magnet and the multipole corrector has an individual bus-bar (28-strand cable). ST with its dedicated bus-bar as well as MC with its dedicated bus-bar have been already discussed in this section.

There are three designs of the cold terminal dedicated for corrector magnets (CS, ST, MC):

- two HTS stacks version (LTS bus-bar connection from the US direction);
- four HTS stacks version (LTS bus-bar connection from the DS direction);
- six HTS stacks version (2 mirrored versions: LTS bus-bar connection from the DS and US direction);.

The detailed schemes of the corrector magnets electrical connections are presented in electrical drawings:

- GSI-SIS100-QDM-1.6A-001 – GSI-SIS100-QDM-1.6A-003;
- GSI-SIS100-QDM-1.7B-001 – GSI-SIS100-QDM-1.7B-003;
- GSI-SIS100-QDM-1.E-001 – GSI-SIS100-QDM-1.E-005;
- GSI-SIS100-QDM-1.Ei-001 – GSI-SIS100-QDM-1.Ei-008;
- GSI-SIS100-QDM-2.4-001 – GSI-SIS100-QDM-2.4-005;

- GSI-SIS100-QDM-2.4x-001 – GSI-SIS100-QDM-2.4x-008;
- GSI-SIS100-QDM-2.5-001 – GSI-SIS100-QDM-2.5-003;
- GSI-SIS100-QDM-2.8C-001 – GSI-SIS100-QDM-2.8C-003;
- GSI-SIS100-QDM-2.9D-001 – GSI-SIS100-QDM-2.9D-003;
- GSI-SIS100-QDM-2.123-001 – GSI-SIS100-QDM-2.123-004.

Connection schemes for LCLs (Cu part + HTS part) and LTS bus-bars dedicated for all QDMs are presented in Figures 37, 38, 39, 40 and 41.

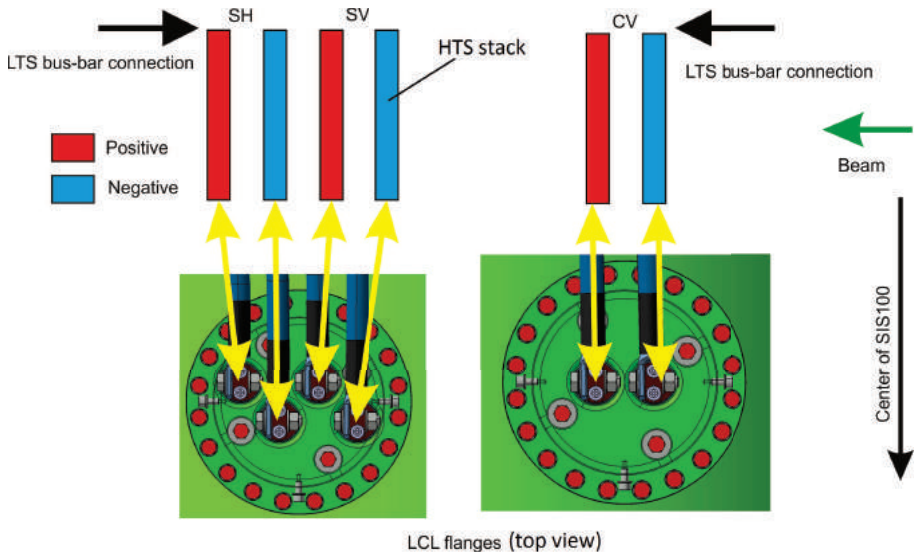


Figure 37: Connection scheme for LCLs (Cu part + HTS part) and LTS bus-bar dedicated for QDMs 2.5 and 1.7B.

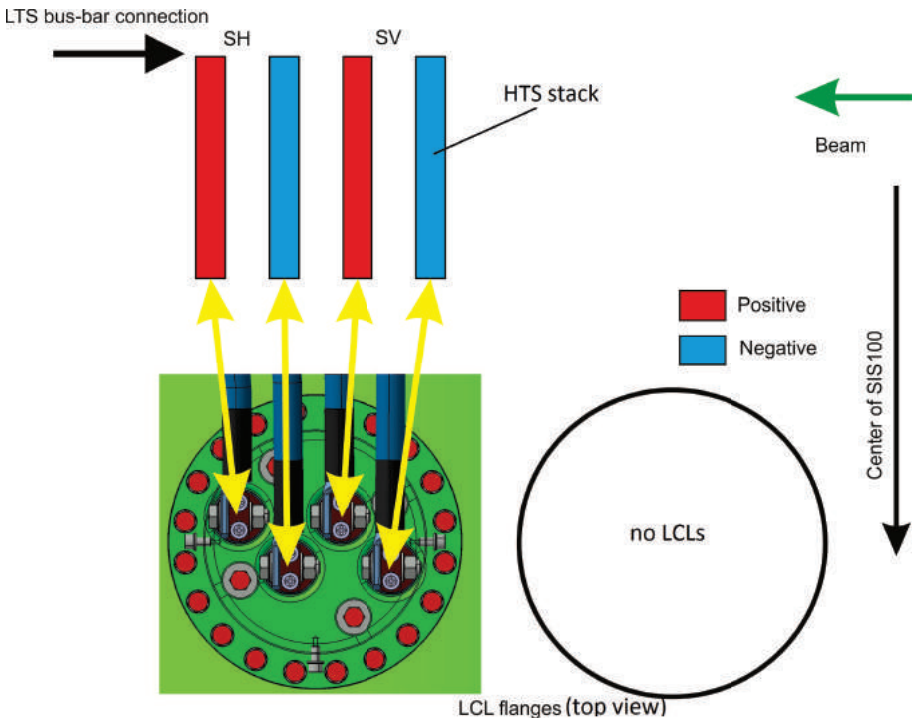


Figure 38: Connection scheme for LCLs (Cu part + HTS part) and LTS bus-bar dedicated for QDMs 2.9D, 2.123 and 2.13s.

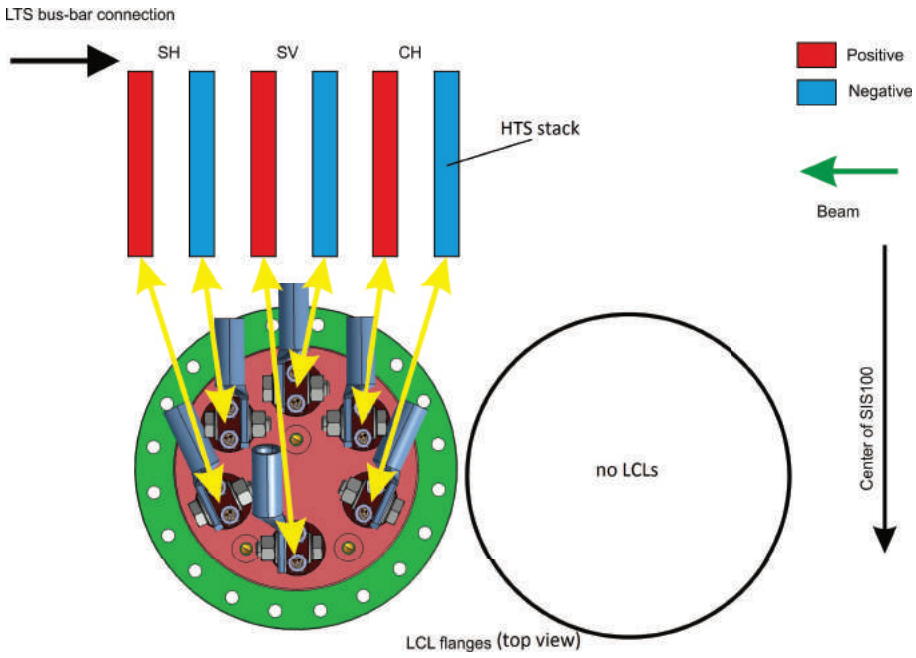


Figure 39: Connection scheme for LCLs (Cu part + HTS part) and LTS bus-bar dedicated for QDMs 1.6A and 2.8C.

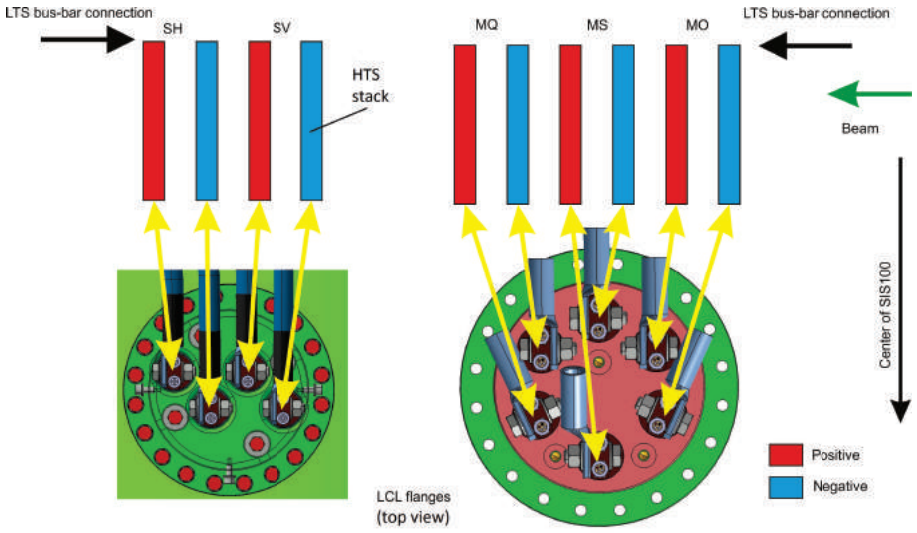


Figure 40: Connection scheme for LCLs (Cu part + HTS part) and LTS bus-bar dedicated for QDMs 1.E and 1.Ei.

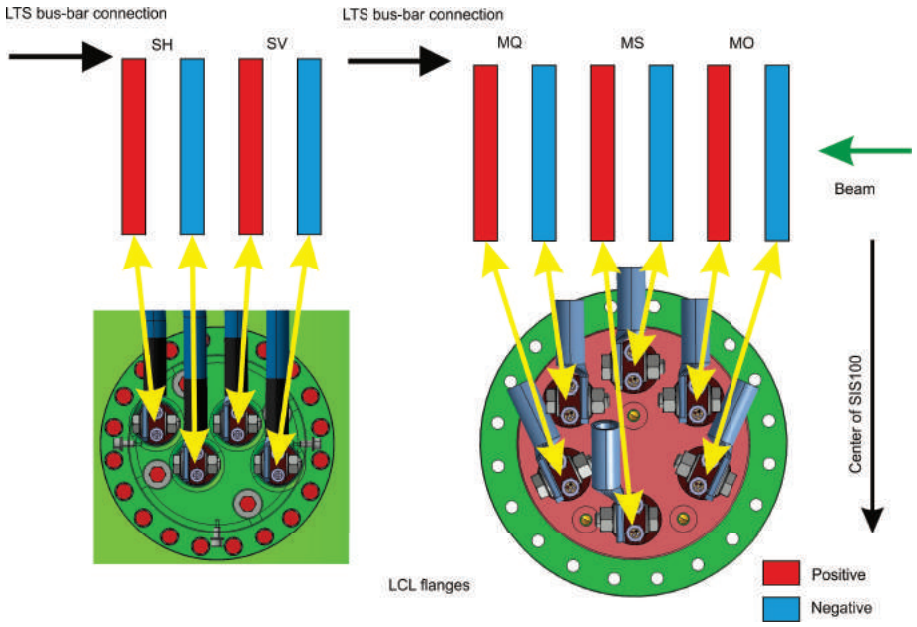


Figure 41: Connection scheme for LCLs (Cu part + HTS part) and LTS bus-bar dedicated for QDMs 2.4 and 2.4x.

4.6.3 Voltage Tap for Low Current Quadrupoles

The local current leads (two pair per LQ magnet), the LQ bus-bar and the LQ coil are electrically connected to each other and they shall be treated as one electric system with common quench detection. The detailed schemes of the corrector magnets electrical connections are presented in electrical drawings:

- GSI-SIS100-QDM-1.Ei-001 – GSI-SIS100-QDM-1.Ei-008;
- GSI-SIS100-QDM-2.4x-001 – GSI-SIS100-QDM-2.4x-008.

The voltage taps are always doubled (i.e: voltage taps 1 and 2 are connected at the same level on the copper part of the positive current lead). The voltage taps shall be soldered in the way that a very good electrical contact is achieved. The soldering shall be reliable and shall withstand the aging process. One shall use Sn96Ag4 soldering and high quality, non-corrosive soldering flux that is suitable for cryogenic temperature. A use of a copper clamp with a pinning hole is recommended. The contractor shall propose the solution for installing the voltage taps (fixation structure). This solution needs to be accepted by the company. After the soldering process, the soldering area shall be insulated with adhesive polyimide tape which will also mechanically fix the voltage tap wire.

In the injection/extraction modules, each low current quadrupole has a dedicated bus-bar (21-strand cable) that connects the LQ coil to the cold terminal of LCL pairs (2 pairs). Four LTS strands that carry the current are soldered to the four HTS stacks. The other six LTS strands are used as a voltage tap wire and bring the electrical potential from the points of interests (located in the terminal box TLQX or TLQY).

The cold terminal dedicated for LQ is very similar to the cold terminal for corrector magnets. Since the 21-strand LQ cable differs from the 28-strand corrector cable the cold terminal for LQ shall be modified to fit the dimensions of the cable and its strands. Fig. 42 shows connection scheme for HTS stacks and Cu parts of LCLs. There are two mirrored versions of cold terminals. The one which has the connection to the LTS-bus-bar from the DS direction and another from the US direction.

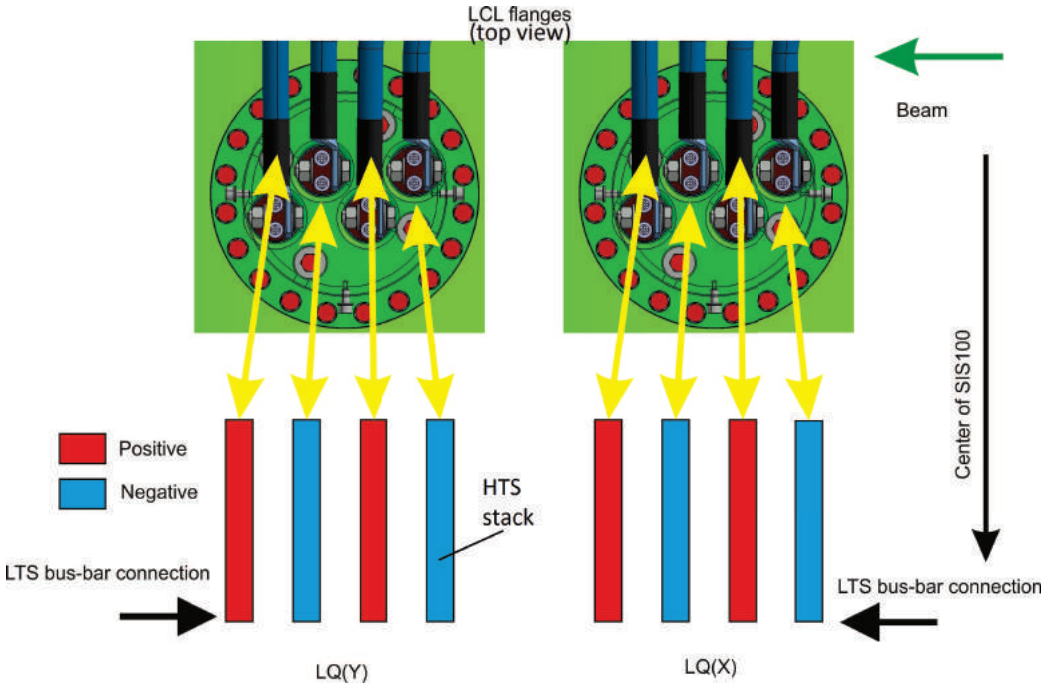


Figure 42: Connection scheme for LCLs (Cu part + HTS part) and LTS bus-bar dedicated for the low current quadrupoles in QDMs 2.4x and 1.Ei.

4.6.4 Voltage Tap Routing and Soldering

To bring the electrical potential from a voltage tap to the voltage tap socket a voltage tap wire is required. When the doublet is assembled, the 6 voltage taps of each quadrupole coil are connected to one socket (named SF1, SF2 or SQD). They shall be bundled and twisted together. The 8 bus-bar voltage taps are connected to another socket (named SBQ). They shall be twisted in pairs (1&2, 3&4, 5&6 and 7&8) and bundled together.

The 18 voltage taps of chromaticity corrector are connected to the SCS socket. 2 x 18 voltage taps of the steering magnet are connected to the SSH (horizontal coil) and SSV (vertical coil) sockets respectively. 3 x 18 voltage taps of the multipole corrector are connected to the SMQ (quadrupole coil), SMS (sextupole coil) and SMO (octupole coil).

30 voltage taps of each low current quadrupole are distributed in two sockets SX1 and SX2 (or SY1 and SY2).

All voltage tap wires that goes to a one socket shall be group together and installed in a shrinking tube. The voltage tap wire length shall be as short as possible and unified for all the wires (unified within the magnet types). The sockets and their connections are presented in electrical drawings:

- GSI-SIS100-QDM-1.6A-001 – GSI-SIS100-QDM-1.6A-003;
- GSI-SIS100-QDM-1.7B-001 – GSI-SIS100-QDM-1.7B-003;
- GSI-SIS100-QDM-1.E-001 – GSI-SIS100-QDM-1.E-005;
- GSI-SIS100-QDM-1.Ei-001 – GSI-SIS100-QDM-1.Ei-008;
- GSI-SIS100-QDM-2.4-001 – GSI-SIS100-QDM-2.4-005;
- GSI-SIS100-QDM-2.4x-001 – GSI-SIS100-QDM-2.4x-008;
- GSI-SIS100-QDM-2.5-001 – GSI-SIS100-QDM-2.5-003;
- GSI-SIS100-QDM-2.8C-001 – GSI-SIS100-QDM-2.8C-003;
- GSI-SIS100-QDM-2.9D-001 – GSI-SIS100-QDM-2.9D-003;
- GSI-SIS100-QDM-2.123-001 – GSI-SIS100-QDM-2.123-004.

Voltage tap sockets are specified in Table 7.

In order to reinforce then pi-to-pin and pin-to-ground insulation in the voltage tap sockets, the soldering side of each socket shall be impregnated with insulation epoxy resin. The epoxy type shall be agreed with the Company. A photo of an electrical feedthrough with upgraded insulation is shown in Fig. 43. The installation procedure can be as following:

- Before soldering of the wires, add a shrinking tube at each of voltage tap wire (each pin shall be covered by 30mm of shrinking tube type ATUM-3/1-0 (Tyco/Raychem) or similar. Next, solder the wires to the corresponding pins. Move the shrinking tubes to the position (extremity) and apply hot air in order to shrink the tubes.
- Add Kapton tape in order to form a ring which will keep the epoxy in place. Immerse the epoxy and wait minimum 48 h.

In order to reduce the static head load caused by voltage tap wires, the wires shall be guided via a heat sink (thermal anchor). The information concerning the thermal anchor is included in the instrumentation lists.

Table 7: Socket names and types

Detection Circuit	Socket name	N° of Vtaps	Socket type	N° of pins
QD coil	SQD	6	Fischer DEE106A007-130	7
F2 coil	SF2	6	Fischer DEE106A007-130	7
F1 coil	SF1	6	Fischer DEE106A007-130	7
Bus-bars	SBQ	8	Fischer DEE106A019-130	8
CS	SCS	18	Fischer DEE107A015-130	19
STV	SSV	18	Fischer DEE107A015-130	19
STH	SSH	18	Fischer DEE107A015-130	19
MQ	SMQ	18	Fischer DEE107A015-130	19
MS	SMS	18	Fischer DEE107A015-130	19
MO	SMO	18	Fischer DEE107A015-130	19
LQX	SX1 and SX2	30	2 x Fischer DEE107A015-130	2 x 19
LQY	SY1 and SY2	30	2 x Fischer DEE107A015-130	2 x 19

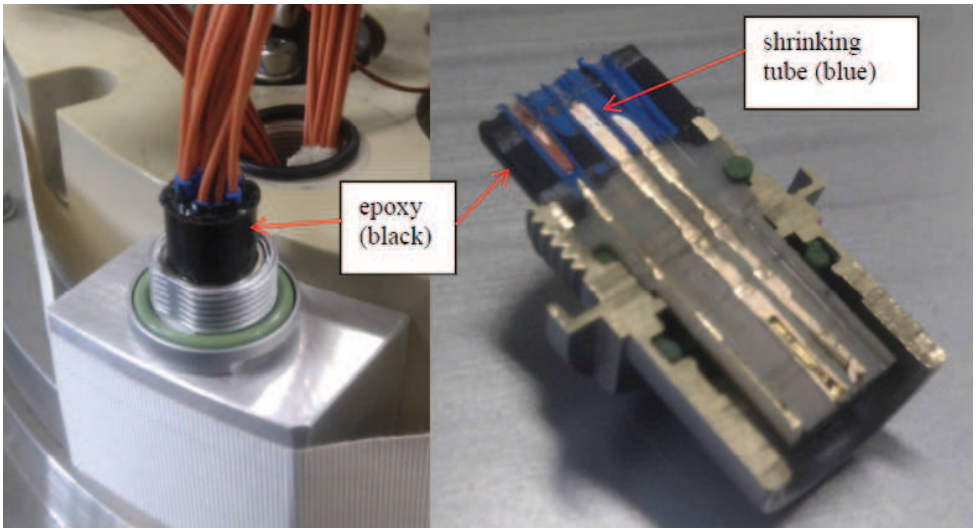


Figure 43: Insulation upgrade at the soldering side of a Fischer socket (photo by CERN).

5 Procedure

5.1 Design Phase

Design related issues are described in [1] and [2] (example of QDM 2.5). All the necessary technical drawings as well as 3D models will be delivered to the contractor by the company. The contractor shall investigate the provided documentation in terms of feasibility.

5.1.1 Design Changes by the Contractor

After approval of a design, changes shall be approved using a change request.

5.1.2 Baking Procedure for the Bus-bars

The baking procedure and related electrical tests shall be described in a work instruction or a test instruction, respectively and they shall be approved by the company.

5.1.3 Design of Special Tooling for Production

In order to produce the required shape of bus-bars, special bending tools are required. The bending tools (chosen by the contractor) shall be accepted by the company.

5.2 Production phase

Production related issues are described in [1] and [2] and documented in drawings listed in section 7 (example of QDM 2.5). The quadrupole coils shall be manufactured in conjunction with the outer bus-bar (one piece of cable) and assembled together with the inner bus-bar. The bus-bar pairs shall be baked together. The bus-bars that are passing through QDM without connection to the quadrupole shall be also baked in pairs.

In case the corrector bus-bars are produce with the same technology as SIS100 corrector coils, all requirements for corrector magnets [10, 11, 12] must by observed. In case that corrector bus-bars are produced with the same technology as SIS100 dipole coil, requirements describe in [15] must by observed. Additionally tests sequence describes in [16] must be applied.

A technical documentation of the production process shall be prepared (in English) by the Contractor and delivered to the Company.

5.2.1 Electrical Connections

The electrical connections of all the magnets including connections inside the terminal boxes of correctors & LQ, bus-bars, connections corrector/LQ bus-bar with cold terminal of LCLs and voltage taps shall be done according to the **latest version** of electrical schemes:

- GSI-SIS100-QDM-1.6A-001 – GSI-SIS100-QDM-1.6A-003;
- GSI-SIS100-QDM-1.7B-001 – GSI-SIS100-QDM-1.7B-003;
- GSI-SIS100-QDM-1.E-001 – GSI-SIS100-QDM-1.E-005;
- GSI-SIS100-QDM-1.Ei-001 – GSI-SIS100-QDM-1.Ei-008;

- GSI-SIS100-QDM-2.4-001 – GSI-SIS100-QDM-2.4-005;
- GSI-SIS100-QDM-2.4x-001 – GSI-SIS100-QDM-2.4x-008;
- GSI-SIS100-QDM-2.5-001 – GSI-SIS100-QDM-2.5-003;
- GSI-SIS100-QDM-2.8C-001 – GSI-SIS100-QDM-2.8C-003;
- GSI-SIS100-QDM-2.9D-001 – GSI-SIS100-QDM-2.9D-003;
- GSI-SIS100-QDM-2.123-001 – GSI-SIS100-QDM-2.123-004.

5.2.2 Labels for Identification of the Main Bus-bars

A special label with short identity symbol (DPo, Dpi, QDo, QDi, F1o , F1i, F2o, F2i and module/unit name i.e. 1.7B) shall be attached to each main bus-bars. Similar labeling shall be used for spare main bus-bars. These labels shall withstand long time storage and cooling down to low temperatures. For example a label could be done with the use of adhesive polyimide tape and permanent marker.

5.2.3 Labels for Identification of the Single Strands of the Correctors (CS, ST, MC) and Injection/Extraction Quadrupoles (LQ)

In case of CS/ST/MC/LQ the connection between the magnet coil and local current leads is done via a LTS bus-bar. This bas-bar is made from the same insulated strand cable as the magnet coil. When the units are manufactured, the LTS bus-bar shall be connected to the terminal box/boxes which is/are part/parts of the magnet. The other end of the bus-bar is open electrically but hydraulically connected to the cold terminal of local current leads which is a part of a unit. In order to identify the strands at the open end of the LTS bus-bar, labels shall be attached. These labels shall contain information about strand names (”a” – ””bb”) according to electrical schemes listed in section 5.2.1.

The labels shall also contain information concerning the magnets that the are connected to, i.e. MC, CV, CH, ST, LQX, LQY. The required label format is as follows: strand identified latter (from ”a” to ”bb”) – connected magnet (MC, CV, CH, ST, LQX, LQY). A few examles of labels are presented below:

- f-ST-CH – strand ”f” of a bus-bar which is connected to the steerer and chromaticity sextupole (horizontal),
- aa-MC – strand ”aa” of a bus-bar which is connected to the multipole corrector,
- x-LQY – strand ”x” of a bus-bar which is connected to the low current quadrupole that sees the beam as the second in the injection/extraction branch.

These labels shall withstand long time storage and cooling down to low temperatures. For example a label could be done with the use of adhesive polyimide tape and permanent marker.

5.2.4 Baking of the Main Bus-bar Pairs

The main bus-bar pairs are baked in order to achieve better mechanical stability. A proposal for the baking procedure (example of the SIS100 dipole) is presented in Table 8. Electrical tests before and after baking shall be performed according to [16].

Table 8: Proposal for the baking procedure for main bus-bars (example of the SIS100 dipole)

Step	Description
1	Preparation: (a) Prepare the prepreg. (b) Cut and bend the bus-bars according to the technical drawings. (c) No damage to the insulation is allowed. (d) Clean and make a visual inspection. (e) Assemble the bus-bars in pairs together with the insulating structure (i.e. G10 or G11) (f) Wrap the prepared bus-bar structure with prepreg
2	Assembly: (a) Put the prepared bus-bar structure into the baking mold. (b) Only straight sections of the bus-bar structure will be baked. (c) Insert the baking mold into the press. (d) Install the heaters (heating rods). (e) Close the press and install the temperature sensor.
3	Apply a pressure of 1.6 bar (0.8 N/mm^2) to the bus-bar structure.
4	Electrical Integrity tests before baking: low voltage tests according to [16].
5	Baking: (a) Heating with 1°C/min from 20°C to 90°C (Pressure 1.6 bar). (b) Wait 10-20 min to stabilize the temperature (±5°C). (c) Further heating, 1.6°C/min, from 90°C to 130°C (Pressure 1.6 bar) (d) Wait 30 min to stabilize the temperature (±5°C). (e) Dimension control.
6	Cooling: (a) After the waiting time, open the press. (b) The structure shall cool down at ambient temperature.
7	Electrical integrity tests after baking: (a) Low voltage tests according to [16]. (b) Test the following circuits: - the inner bus-bar to the outer bus-bar; - the inner bus-bar to the baking mold (ground); - the outer bus-bar to the baking mold (ground).
8	Disassembly: Disassemble heaters and the baking mold.

5.2.5 Place for Superconducting Joints on the Main Bus-bars

The place for superconducting joints shall be prepared by the contractor. The procedure is as following:

- first add adhesive polyimide tape (or another insulating tape which is radiation hard) on both ends of the area,
- remove the insulation over 150 mm,
- solder the fixation wire (NiCr) over 3-5 mm on each end (AG96Ag4 soldering with high quality flux, non-corrosive flux),
- finally remove the NiCr wire over 140 mm,
- in case of storage or transportation, the joint area shall be secured against dust and mechanical damages with 5-10 layers of PCV/plastic foil.

5.2.6 Ends of Main Bus-bars

The ends of main bus-bars shall be prepared for the integration to the cryogenic system. The procedure is as following:

- first add adhesive polyimide tape (or another insulating tape which is radiation hard),
- secure the fixation and superconducting wires by soldering (AG96Ag4 soldering with high quality flux, non-corrosive flux),
- remove everything (insulation, NiCr, superconducting strands) up to the tube,
- further steps in order to integrate the end of bus-bar with cryogenic system,
- in case of storage or transportation, the bus-bar end area shall be secured against dust and mechanical damages with 5-10 layers of PCV/plastic foil.

5.2.7 Electrical Integrity tests during production

The sequence of electrical tests presented in [16] must be applied. More detailed information about tests performance, analysis and acceptance criteria are described in related technical guideline [15, 17, 18]. Following requirements for electrical tests must be applied for this stage:

1. Low voltage tests before baking must be defined experimentally.
2. Low voltage tests after baking must be repeated to compare results; acceptance criteria must be proved experimentally by means of samples and test coils.
3. Test voltages after baking (room temperature):
    - 3 kV (in steps 600 V, 1.5 kV, 3 kV) for dipole and quadrupole and related bus-bars - the maximum leakage current shall be lower than 150 nA at 3 KV / 2 min,
    - 1.1 kV (in steps 200 V, 600V, 1.1 kV) for correctors - the maximum leakage current shall be lower than 1 μA at 1.1 KV / 2 min,
    - 1.1 kV (in steps 200 V, 600V, 1.1 kV) for corrector bus-bars - the maximum leakage current shall be lower than 1 μA at 1.1 KV / 2 min.

4. Test of temperature sensors (if applicable) is described in [16].
5. Test the following circuits:
    - the inner bus-bar to the outer bus-bar,
    - the inner bus-bar to the baking mold (ground),
    - the outer bus-bar to the baking mold (ground),
    - each strand to NiCu tube (correctors),
    - each strand to baking mold (correctors) - if applicable,
    - between neighboring strands (correctors).

6 Quality assurance, tests, and acceptance

This detailed specification concerns quadrupole doublet modules (QDMs). Prior to assembly of the quadrupole doublet modules, first the quadrupole units have to be manufactured, tested and accepted. Therefore this section is devided into two parts. One part concerns the units (FAT and SAT), the other concerns quadrupole doublet modules (FAT and SAT).

6.1 Quality Assurance (QA) System of the Contractor (Units)

Prior to assembly of the units into the modules, each unit shall pass the acceptance test. In case of a unit fails the acceptance test, such a unit shall not be shipped and Non Conformity Report (NCR) is required. Units (quadrupole magnets and their bus-bars, corrector magnets and their bus-bars) shall be tested at the contractor site. The quality assurance issues are treated widely in [1] (QA section) and [2] (QDM 2.5 example). The test program for the quadrupole units is described in [20]. The contractor shall prepare the infrastructure and interfaces for the unit testing as follows:

- main current leads for quadrupoles (in case of testing at the operating temperature 4 K);
- local current leads (for correctors) (in case of testing at the operating temperature 4 K);
- connection interfaces between current leads and magnets (quadrupoles, correctors);
- power converters for magnet powering;
- quench protection system elements (energy extraction resistors) - in case of testing at the operating temperature 4 K;
- quench detection (in case of testing at the operating temperature 4 K);
- cooling infrastructure (cryostat, etc.) - in case of testing at the operating temperature 4 K;
- equipment for pressure test.

6.2 Factory Acceptance Test (FAT) of the Units

For all tests concerning FAT, a test report shall be created by the contractor (in English) and it shall be delivered to the company. Inspection/measurement protocols shall be attached to this report. The test objects are rejected if they do not pass all the tests listed in section 6.2.

6.2.1 Visual Inspection (FAT of the Units)

For visual inspection, a least the following details shall be verified:

- insulation damage,
- any other damage (mechanical),
- change of color,
- corrosion of metal,
- plastic deformation,
- correctness of electrical connections,

- presence and soldering quality of voltage taps,
- voltage tap labels and their correctness,
- presence of labels that identify main bus-bars,
- presence of labels that identify single strands in the bus-bars of correctors/LQs (to be installed at the bus-bar extremity which will be later connected to the cold terminal of local current leads, according to section 5.2.3).

Photos shall be taken and submitted. Each defect shall be documented and reported to the company. The company has the right to reject the unit due to the defect or ask for repair.

6.2.2 Pressure Test (FAT of the Units)

Main bus-bars, main magnet coils, cooling channels of magnetic yokes, corrector bus-bars, corrector coils, terminal boxes and cold terminals of local current leads are part of the helium supply system. Therefore an adequate pressure test shall be performed according to the AD2000 code of practice for pressure vessels (test condition: maximum allowed working pressure x 1.43). The object will be rejected if it does not pass the pressure test.

6.2.3 Electrical Tests at Room Temperature (FAT of the Units)

Electrical tests to be performed on magnets are described in [9, 10, 11, 12]. More detailed information about tests performance, analysis and acceptance criteria are described in related technical guideline [15, 17, 18]. The sequence of electrical tests presented in [16] must be observed. Following electrical tests and related actions shall be applied to the units:

- Check for correctness of the magnets polarity (QD, F1, F2, CS, SV, SH, MC, QJ, LQ)
- DC high voltage tests at 3 kV/120 s; applied to main magnets circuits[2]: life-circuit to ground, life circuit to another life-circuit; the maximum leakage current shall be lower than 150 nA at 3 KV / 2 min.
- DC high voltage tests at 1.1 kV/120 s; applied to corrector/LQ circuits[3]: life-circuit to ground, life circuit to another life-circuit; the maximum leakage current shall be lower than 1 μA at 1.1 KV / 2 min.
- AC and capacitor discharge tests according to [16].
- Additional low voltage tests according to [16].
- Continuity test of voltage taps - in order to check the correct order and presence of voltage taps: applied to all circuits.
- Test of temperature sensors (if applicable) according to [15].
- Correctness of labels that identify single strands in the bus-bars of correctors/LQs (to be installed at the bus-bar extremity which will be later connected to the cold terminal of local current leads, according to section 5.2.3).

The object will be rejected if it does not pass the electrical tests presented in section 6.2.3.

[2] Main circuit is: (a) a qudrupole magnet with the outer busbar, (b) any main bus-bar (units testing).

[3] Corrector/LQ circuit is the corrector/LQ magnet including terminal box/boxes and corrector/LQ bus-bar + cold terminal of LCLs (units testing).

6.3 Site Acceptance Test (SAT) of the Units

All the incoming goods shall be inspected in terms of: the proper size/shape, tolerances, cleanliness and accordance with the design. The goods will be rejected if they do not pass this inspection.

For all tests concerning SAT, a test report shall be created (in English). Inspection/measurement protocols shall be attached to this report. The test objects are rejected (a Non Conformity Report shall be created) if they do not pass all the tests listed in section 6.3.

6.3.1 Visual Inspection (SAT of the Units)

For visual inspection, a least the following details shall be verified:

- insulation damage,
- any other damage (mechanical),
- change of color,
- corrosion of metal,
- plastic deformation,
- correctness of electrical connections,
- presence and soldering quality of voltage taps,
- presence of labels that identify main bus-bars,
- voltage tap labels and their correctness,
- labels that identify single strands in the bus-bars of correctors/LQs (to be installed at the bus-bar extremity which will be later connected to the cold terminal of local current leads).

Photos shall be taken and submitted. Each defect shall be documented and reported to the company. The company has the right to reject the unit due to the defect or ask for repair.

6.3.2 Pressure Test (SAT of the Units)

Main bus-bars, main magnet coils, cooling channels of magnetic yokes, corrector bus-bars, corrector coils, terminal boxes and cold terminals of local current leads are part of the helium supply system. Therefore an adequate pressure test shall be performed according to the AD2000 code of practice for pressure vessels (test condition: maximum allowed working pressure x 1.43). The object will be rejected if it does not pass the pressure test.

6.3.3 Electrical Tests at Room Temperature (SAT of the Units)

Electrical tests to be performed on magnets are described in [9, 10, 11, 12]. More detailed information about tests performance, analysis and acceptance criteria are described in related technical guideline [15, 17, 18]. The sequence of electrical tests presented in [16] must be observed. Following electrical tests and related actions shall be applied to the units:

- Check for correctness of the magnets polarity (QD, F1, F2, CS, SV, SH, MC, QJ, LQ)

- DC high voltage tests at 3 kV/120 s; applied to main magnets circuits[4]: life-circuit to ground, life circuit to another life-circuit; the maximum leakage current shall be lower than 150 nA at 3 KV / 2 min.
- DC high voltage tests at 1.1 kV/120 s; applied to corrector/LQ circuits[5]: life-circuit to ground, life circuit to another life-circuit; the maximum leakage current shall be lower than 1 μA at 1.1 KV / 2 min.
- AC and capacitor discharge tests according to [16].
- Additional low voltage tests according to [16].
- Continuity test of voltage taps - in order to check the correct order and presence of voltage taps: applied to all circuits.
- Test of temperature sensors (if applicable) according to [15].
- Correctness of labels that identify single strands in the bus-bars of correctors/LQs (to be installed at the bus-bar extremity which will be later connected to the cold terminal of local current leads, according to section 5.2.3).

The object will be rejected if it does not pass the electrical tests presented in section 6.3.3.

6.3.4 Electrical Tests at Cold Conditions (SAT of the Units)

The sequence of electrical tests presented in [16] must be observed. Following electrical tests and related actions shall be applied to the units:

- DC high voltage tests at 3 kV/120 s; applied to main magnets circuits[4]: life-circuit to ground, life circuit to another life-circuit; acceptance criteria: insulation resistance is 20 GΩ for life circuit not connected to power circuit of test bench and 1.1 GΩ or more when is connected.
- DC high voltage tests at 1.1 kV/120 s; applied to corrector/LQ circuits[5]: life-circuit to ground, life circuit to another life-circuit; acceptance criteria: insulation resistance is 20 GΩ for life circuit not connected to power circuit of test bench and 1.1 GΩ or more when is connected.
- AC and capacitor discharge tests according to [16].
- Additional low voltage tests according to [16].
- Continuity test of voltage taps - in order to check the correct order and presence of voltage taps: applied to all circuits.
- Test of temperature sensors (if applicable) according to [15].

More detailed information about tests performance, analysis and acceptance criteria are described in related technical guideline [15, 17, 18]. The object will be rejected if it does not pass the electrical tests presented in section 6.6.4.

6.3.5 Magnet Training (SAT of the Units)

Clear acceptance criteria regarding the quench performance in all magnets are presented in the FAIR technical guideline [19].

[4]Main circuit is: (a) a qudrupole magnet with the outer busbar, (b) any main bus-bar (units testing).

[5]Corrector/LQ circuit is the corrector/LQ magnet including terminal box/boxes and corrector/LQ bus-bar + cold terminal of LCLs (units testing).

6.3.6 Operation at cold conditions (SAT of the Units)

Investigation of the system operation at cold conditions: all the circuits shall be checked for the correct operation at nominal parameters (nominal currents, ramp rates, etc.). If during operation at nominal conditions some disturbances occur (i.e. quench in a bus-bar when it is well cooled) or object could not reach its nominal parameters, the company has the right to reject the object or ask the contractor for repair.

6.3.7 Electrical Tests at Room Temperature After Warm Up (SAT of the Units)

Electrical tests to be performed on magnets are described in [9, 10, 11, 12]. More detailed information about tests performance, analysis and acceptance criteria are described in related technical guideline [15, 17, 18]. The sequence of electrical tests presented in [16] must be observed. Following electrical tests and related actions shall be applied to the units:

- DC high voltage tests at 3 kV/120 s; applied to main magnets circuits[6]: life-circuit to ground, life circuit to another life-circuit; the maximum leakage current shall be lower than 150 nA at 3 KV / 2 min.
- DC high voltage tests at 1.1 kV/120 s; applied to corrector/LQ circuits[7]: life-circuit to ground, life circuit to another life-circuit; the maximum leakage current shall be lower than 1 μA at 1.1 KV / 2 min.
- Continuity test of voltage taps - in order to check the correct order and presence of voltage taps: applied to all circuits.
- Test of temperature sensors (if applicable) according to [15].

If the object does not pass the electrical tests presented in section 6.3.7, it will be rejected or the contractor will be asked for repair.

[6] Main circuit is: (a) a qudrupole magnet with the outer busbar, (b) any main bus-bar (units testing).

[7] Corrector/LQ circuit is the corrector/LQ magnet including terminal box/boxes and corrector/LQ bus-bar + cold terminal of LCLs (units testing).

6.4 Quality Assurance System of the Contractor (Quadrupole Doublet Modules)

After acceptance of the units, they will be assembled into quadrupole doublet modules (QDMs). Requirements for the unit integration into a module can be found in [2] (example of QDM 2.5) and in [1] in the quality assurance section. The test program for the quadrupole units is described in [21].

6.5 Factory Acceptance Test (FAT) of the QDMs

All the incoming goods shall be inspected in terms of: the proper size/shape, tolerances, cleanliness and accordance with the design. The goods will be rejected if they do not pass this inspection.

For all tests concerning FAT, a test report shall be created by the contractor (in English) and it shall be delivered to the company. Inspection/measurement protocols shall be attached to this report. The test objects are rejected (a Non Conformity Report shall be created) if they do not pass all the tests listed in section 6.5.

6.5.1 Visual Inspection (FAT of QDMs)

For visual inspection, a least the following details shall be verified:

- insulation damage,
- any other damage (mechanical),
- change of color,
- corrosion of metal,
- plastic deformation,
- presence and soldering quality of voltage taps,
- presence of labels that identify main bus-bars,
- voltage tap labels and their correctness.

Photos shall be taken and submitted. Each defect shall be documented and reported to the company. The company has the right to reject the unit due to the defect/defects and ask for repair.

6.5.2 Pressure Test (FAT of QDMs)

Main bus-bars, main magnet coils, cooling channels of magnetic yokes, corrector bus-bars, corrector coils, terminal boxes and cold terminals of local current leads are part of the helium supply system. Therefore an adequate pressure test shall be performed according to the AD2000 code of practice for pressure vessels (test condition: maximum allowed working pressure x 1.43). The object will be rejected if it does not pass the pressure test.

6.5.3 Electrical Tests at Room Temperature (FAT of QDMs)

Electrical tests to be performed on magnets are described in [9, 10, 11, 12]. More detailed information about tests performance, analysis and acceptance criteria are described in related technical guidelines [15, 17, 18]. The sequence of electrical tests presented in [16] must be observed. Following electrical tests and related actions shall be applied to the units:

- Check for correctness of the magnets polarity (QD, F1, F2, CS, SV, SH, MC, QJ, LQ)
- DC high voltage tests at 3 kV/120 s; applied to main magnets circuits[8]: life-circuit to ground, life circuit to another life-circuit; the maximum leakage current shall be lower than 150 nA at 3 KV / 2 min.
- DC high voltage tests at 1.1 kV/120 s; applied to corrector/LQ circuits[9]: life-circuit to ground, life circuit to another life-circuit; the maximum leakage current shall be lower than 1 μA at 1.1 KV / 2 min.
- AC and capacitor discharge tests according to [16].
- Additional low voltage tests according to [16].
- Continuity test of voltage taps - in order to check the correct order and presence of voltage taps: applied to all circuits.
- Test of temperature sensors (if applicable) according to [15].
- Correctness of labels that identify single strands in the bus-bars of correctors/LQs (to be installed at the bus-bar extremity which will be later connected to the cold terminal of local current leads, according to section 5.2.3).

The object will be rejected if it does not pass the electrical tests presented in section 6.5.3.

6.6 Site Acceptance Test (SAT) of the QDMs

All the incoming goods shall be inspected in terms of: the proper size/shape, tolerances, cleanliness and accordance with the design. The goods will be rejected if they do not pass this inspection.

For all tests concerning SAT, a test report shall be created by the contractor (in English) and it shall be delivered to the company. Inspection/measurement protocols shall be attached to this report. The test objects are rejected (a Non Conformity Report shall be created) if they do not pass all the tests listed in section 6.6.

6.6.1 Visual Inspection (SAT of QDMs)

For visual inspection, a least the following details shall be verified:

- insulation damage,
- any other damage (mechanical),
- change of color,
- corrosion of metal,
- plastic deformation,
- presence and soldering quality of voltage taps,
- presence of labels that identify main bus-bars,
- voltage tap labels and their correctness.

Photos shall be taken and submitted. Each defect shall be documented and reported to the company. The company has the right to reject the unit due to the defect/defects and ask for repair.

[8] Main circuit is: (a) a qudrupole magnet with the outer busbar, (b) any main bus-bar (QDMs testing).
[9] Corrector/LQ circuit is the corrector/LQ magnet including terminal box/boxes, corrector/LQ bus-bar and LCLs (QDMs testing).

6.6.2 Pressure Test (SAT of QDMs)

Main bus-bars, main magnet coils, cooling channels of magnetic yokes, corrector bus-bars, corrector coils, terminal boxes and cold terminals of local current leads are part of the helium supply system. Therefore an adequate pressure test shall be performed according to the AD2000 code of practice for pressure vessels (test condition: maximum allowed working pressure x 1.43). The object will be rejected if it does not pass the pressure test.

6.6.3 Electrical Tests at Room Temperature (SAT of QDMs)

Electrical tests to be performed on magnets are described in [9, 10, 11, 12]. More detailed information about tests performance, analysis and acceptance criteria are described in related technical guideline [15, 17, 18]. The sequence of electrical tests presented in [16] must be observed. Following electrical tests and related actions shall be applied to the units:

- Check for correctness of the magnets polarity (QD, F1, F2, CS, SV, SH, MC, QJ, LQ)
- DC high voltage tests at 3 kV/120 s; applied to main magnets circuits[10]: life-circuit to ground, life circuit to another life-circuit; the maximum leakage current shall be lower than 150 nA at 3 KV / 2 min.
- DC high voltage tests at 1.1 kV/120 s; applied to corrector/LQ circuits[11]: life-circuit to ground, life circuit to another life-circuit; the maximum leakage current shall be lower than 1 μA at 1.1 KV / 2 min.
- AC and capacitor discharge tests according to [16].
- Additional low voltage tests according to [16].
- Continuity test of voltage taps - in order to check the correct order and presence of voltage taps: applied to all circuits.
- Test of temperature sensors (if applicable) according to [15].
- Correctness of labels that identify single strands in the bus-bars of correctors/LQs (to be installed at the bus-bar extremity which will be later connected to the cold terminal of local current leads, according to section 5.2.3).

The object will be rejected if it does not pass the electrical tests presented in section 6.6.3.

6.6.4 Electrical Tests at Cold Conditions (SAT of QDMs)

The sequence of electrical tests presented in [16] must be observed. Following electrical tests and related actions shall be applied to the units:

- DC high voltage tests at 3 kV/120 s; applied to main magnets circuits[12]: life-circuit to ground, life circuit to another life-circuit; acceptance criteria: insulation resistance is 20 GΩ for life circuit not connected to power circuit of test bench and 1.1 GΩ or more when is connected.
- DC high voltage tests at 1.1 kV/120 s; applied to corrector/LQ circuits[13]: life-circuit to ground, life circuit to another life-circuit; acceptance criteria: insulation resistance is 20 GΩ for life circuit not connected to power circuit of test bench and 1.1 GΩ or more when is connected.

[10] Main circuit is: (a) a qudrupole magnet with the outer busbar, (b) any main bus-bar (QDMs testing).
[11] Corrector/LQ circuit is the corrector/LQ magnet including terminal box/boxes, corrector/LQ bus-bar and LCLs (QDMs testing).
[12] Main circuit is: (a) a qudrupole magnet with the outer busbar, (b) any main bus-bar (QDMs testing).
[13] Corrector/LQ circuit is the corrector/LQ magnet including terminal box/boxes, corrector/LQ bus-bar and LCLs (QDMs testing).

- AC and capacitor discharge tests according to [16].
- Additional low voltage tests according to [16].
- Continuity test of voltage taps - in order to check the correct order and presence of voltage taps: applied to all circuits.
- Test of temperature sensors (if applicable) according to [15].

More detailed information about tests performance, analysis and acceptance criteria are described in related technical guideline [15, 17, 18]. The object will be rejected if it does not pass the electrical tests presented in section 6.6.4.

6.6.5 Operation at cold conditions (SAT of QDMs)

Investigation of the system operation at cold conditions: all the circuits shall be checked for the correct operation at nominal parameters (nominal currents, ramp rates, etc.). If during operation at nominal conditions some disturbances occur (i.e. quench in a bus-bar when it is well cooled) or object could not reach its nominal parameters, the company has the right to reject the object or ask the contractor for repair.

6.6.6 Electrical Tests at Room Temperature After Warm Up (SAT of QDMs)

Electrical tests to be performed on magnets are described in [9, 10, 11, 12]. More detailed information about tests performance, analysis and acceptance criteria are described in related technical guideline [15, 17, 18]. The sequence of electrical tests presented in [16] must be observed. Following electrical tests and related actions shall be applied to the units:

- DC high voltage tests at 3 kV/120 s; applied to main magnets circuits[12]: life-circuit to ground, life circuit to another life-circuit; the maximum leakage current shall be lower than 150 nA at 3 KV / 2 min.
- DC high voltage tests at 1.1 kV/120 s; applied to corrector/LQ circuits[13]: life-circuit to ground, life circuit to another life-circuit; the maximum leakage current shall be lower than 1 μA at 1.1 KV / 2 min.
- Continuity test of voltage taps - in order to check the correct order and presence of voltage taps: applied to all circuits.
- Test of temperature sensors (if applicable) according to [15].

If the object does not pass the electrical tests presented in section 6.6.6, it will be rejected or the contractor will be asked for repair.

7 Documentation

The contractor shall respect these design basics. Table 9 gives related drawings numbers. This drawings concern QDM 2.5. Further drawings concerning all QDMS will be delivered later.

Table 9: List of Supplementary Drawings

Drawing Number	Title
MG-1005150-A-000	Quadrupole Doublet type 2.5. Sensor application
MAG-V08-E66.000.000	SF2B unit
MAG-V08-E66.020.000	F1o, F1i, F2o and F2i bus-bars
MAG-V08-E66.033.000	F1o and F1i bus-bars
MAG-V08-E66.034.000	F2o and F2i bus-bars
MAG-V04-E66.000.000	VQD unit
MAG-V04-E66.020.000	QDo, QDi, DPo and DPi bus-bars
MAG-V04-E66.031.000	DPo and DPi bus-bars
MAG-V04-E66.032.000	QDo and QDi bus-bars
MG-1009693-A-V01	Terminal box for corrector magnets
MAG-V07-D96.000.000	Steering magnet
MAG-V08-D76.000.000	Chramaticity sextupole magnet

8 Related Documents

References

[1] Mandatory: General Specification, F-GS-F-01e-General_Specification_v1_2

[2] Mandatory: Specification for Production and Delivery of Quadrupole Units for integration in the SIS100-Quadrupole doublet Module, Type 2.5, F-DS-MT-81e

[3] Recommended: FAIR Technical Guideline: Magnet drawing axes, F-TG-MT-2.39e

[4] Recommended: Detailed Specification of Low Loss Superconducting Strand for SIS100 Main Magnets, F-DS-MT-66e

[5] Recommended: Detailed Specification of Insulated Superconducting strand for SIS100 Corrector Magnets, F-DS-MT-75e

[6] Mandatory: Detailed Specification of the Cooling System of the Regular Arc Quadrupole Modules for SIS100, F-DS-MT-71e

[7] Mandatory: Detailed Specification of the Cooling System of the Quadrupole Modules in the Straight Sections of SIS100, F-DS-MT-79e

[8] Mandatory: Detailed Specification of the Cooling System of the Arc Termination Quadrupole Modules for SIS100, F-DS-MT-83e

[9] Mandatory: Detailed Specification of SIS100 Quadrupole Magnet, F-DS-MT-48e

[10] Mandatory: Detailed Specification of SIS100 Chromaticity Sextupole Magnet, F-DS-MT-52e

[11] Mandatory: Detailed Specification of SIS100 Steering Magnet, F-DS-MT-51e

[12] Mandatory: Detailed Specification of SIS100 Multipole Corrector Magnet, F-DS-MT-53e

[13] Mandatory: Detailed Specification of SIS100 SIS100 Low Current Quadrupole, F-DS-MT-50e

[14] Mandatory: Detailed specification for conduction cooled local current leads for SIS100, F-DS-MT-47e

[15] Mandatory: FAIR Technical Guideline: DC High Voltage Insulation Tests for SC Magnets, F-TG-MT-01e

[16] Mandatory: FAIR Technical Guideline: Sequence of Electrical Integrity Tests for Testing of SC Magnets, F-TG-MT-7.35e

[17] Mandatory: FAIR Technical Guideline: Turn-to-Turn Insulation Test of Magnet Coil by Means of Capacitor Discharge, F-TG-MT-7.33e

[18] Mandatory: FAIR Technical Guideline: Electrical Continuity Test of Magnet Circuits, F-TG-MT-7.34e

[19] Mandatory: FAIR Technical Guideline: Training of Superconducting Magnets, F-TG-MT-7.36e

[20] Mandatory: Detailed Specification on Testing of Superconducting Quadrupole Units for the SIS100, F-DS-MT-86e

[21] Mandatory: Detailed Specification on Testing of Superconducting Quadrupole Doublet Modules for the SIS100, F-DS-MT-85e