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Abbreviations and Definitions

CID	Component Identifier
DAQ	Data Acquisition
DMM	Digital Multimeter
DP	Dipole
DPM	Dipole Module
EI	Electrical Integrity
FAIR	Facility for Antiproton and Ion Research
GSI	GSI Helmholtzzentrum für Schwerionenforschung GmbH
HV	High Voltage
IF	Instrumentation Flange
LV	Low Voltage
MDM	Missing Dipole Module
NCR	Nonconformity report
PE	Protective Earth
QA	Quality Assurance
QuD	Quench Detection
R_x	Electrical Resistance; unit Ohm
SAT	Site Acceptance Test
sc	superconducting
SIS100	Heavy Ion Synchrotron 100 (rigidity)
STF	Series Test Facility
SV	Step Voltage, a HV test sequence
T	Temperature; symbol for physical quantity; unit Celsius or Kelvin
TBD	to be defined
TC	Thermocouple
VT	Voltage Tap, wire connected to the “live circuit” for quench detection
WPL	Work Package Leader

1. Purpose and Scope

SIS100 is the accelerating part of the new FAIR research centre, now ready for components installation at the beamline, beginning from its sector 4 in building K0923A.U30. The beamline comprises superconducting (sc) dipole magnets for bending the beam, quadrupole modules containing multiple corrector magnets and so-called local cryogenics providing sc-bus-bar structures as well as current leads. Installation will start with SIS100 dipole modules and proceed clockwise through all six sectors.

The purpose of this technical guideline is to outline the **Electrical Integrity (EI)** tests **exclusively for SIS100 dipole modules** (DPM) within the framework of their upcoming tunnel integration. This also includes the so called "**Missing Dipole Modules**" (MDM), which basically are a SIS100 dipole module without dipole coil and yoke, just containing the sc-bus-bar pairs to forward the main magnet circuits operating current.



Figure 1: SIS100 dipole modules in the accelerator tunnel

Up to now, testing experience is limited to stand-alone units during their site acceptance test procedure and the "short string test" within a defined and clear test facility environment. An electrical integrity test scenario considering the technical, environmental and logistics demands of a much more complex arrangement within an accelerator tunnel while simultaneous installation activities are in progress, is not developed yet.

An essential **EI-Start-Scenario** shall be at least an "Incoming Electrical Inspection" of each stand-alone device performed at its final installation location. Following storage, transportation and insertion into the tunnel, this is required to determine the remaining electrical insulation quality of the object, detecting possible damages to the instrumentation and to grant the "**Approval for further Installation**".

Locating issues within a combined system of multiple sc-modules appears to be very time-consuming possibly leading to uncertain results and shall be subject to future investigations. Anyway, a first introduction is given for **EI-testing on dipole modules in pairs**.

2. Requirements and Limitations

For safe operation and less troubleshooting during later commissioning of sc-magnets/modules, a minimum electrical integrity of stand-alone objects or modules in pairs as stated in the acceptance criteria is mandatory.

Therefore, a "**tracking folder**" shall be available, attached to every SIS100 DPM and MDM. This folder shall at least contain an approved test plan and test instructions. Moreover, the object test protocol including a results summary and tester's signatures shall be filed here. A benefit would be electrical schematics of the object and the calibration data of each associated sensor on a data medium as well as its final STF outgoing inspection protocol for comparison.

Prior to any testing or installation of a component at the beamline, a **visual inspection, thorough cleaning, purging** and crosscheck of the latest acceptance protocols is highly recommended.

HV/LV-insulation tests shall be performed prior to functional tests due to the risk of instrumentation damage. The **sequence of electrical tests on stand-alone objects** shall be as indicated in the following table:

Seq.	**Incoming inspection** on stand-alone objects @ ambient temperature **(~ 293 K**)	**Remarks**
1	Visual inspection of electrical installation	sockets, plugs, wires, bus-bars, grounding, etc.
2	High voltage (HV) insulation test	SV - step voltage test up to **2000 V**
3	Low voltage (LV) test on sensors & heaters	heater cartridge: heater unit @ 100 V & TC @ 50 V
4	Fast continuity test after HV-test	2-wire method
5	Sensor alive test after HV-test	consider temperature deviation from reference 293 K
6	Approval for further installation	next step: connection of dipole modules in pairs

Table 1: Electrical integrity tests sequence on stand-alone SIS100 DPM/MDM

Observing the environmental conditions inside, outside and around a test object is essential for meaningful test results. Test procedures and results largely vary with respect to humidity and temperature. As far as possible, all testing of stand-alone dipoles at the beamline shall be executed at **ambient conditions**, i.e. 18 °C ± 5 °C outside respectively 291 K ± 5 K inside an object under test. The suggested range intends to cover the hardly predictable real temperature in the beam tunnel during installation phase, which might appear rather on the chilly side. The assumption also is an appropriate settling time of the devices under test. Temperature and humidity around the test area shall be recorded in the test protocol.

Another limiting factor, in particular for HV-insulation testing on the spot, might be the **remaining humidity** in the new FAIR beam tunnel. SAT experience so far indicates, at humidity of ≥ 40% rel. around the object, clear HV test results become less probable while testing an exposed stand-alone module at ambient conditions. Therefore, high humidity occasionally requires covering and/or **extensive drying actions** (e.g. voltage breakers, connectors) prior to testing. Moreover, due to hygroscopic behaviour of materials, HV-testing might not be feasible at all. No HV-tests can be performed below the so called "**dew point**" temperature. Evaluation of the object status and tunnel environment is subject to review by an experienced test expert.

Attention:

This guideline does NOT contain detailed work instructions yet. Test setup, test procedures, electrical safety, acceptance criteria and major aspects concerning the verification of electrical integrity at superconducting (sc) modules need to be known to the operators. **Therefore, testing is restricted to electrically qualified experts of the SCM department or electrically instructed persons under their supervision.**

3. Safety Aspects

Personnel and equipment safety is of paramount importance while performing electrical integrity tests on accelerator components. Observing the following safety measures is **mandatory**:

- Electrically qualified and instructed personnel only shall conduct electrical integrity tests and operate electrical test equipment.
- Valid standards and accident prevention regulations concerning the specific work environment and working conditions have to be considered. Therefore, a risk assessment for electrical work in the beam tunnel shall be conducted and personnel shall be instructed on local conditions in the building.
- Use dedicated, certified and calibrated test equipment only. Be sure that **all** test accessory is suitable and in perfect condition. Moreover, it is mandatory to read operating manuals, in particular for HV generating devices.
- Never work alone at a test object. At least teams by two are required to give aid in case of an emergency. First-aid and fire protection training of test personnel is requested.
- Grounding (to PE, protective earth) of the test object (i.e. the cryostat vessel) and corresponding support structure is mandatory. Moreover, discharging the test circuit (e.g. by shorting and/or shorting to ground) is of vital importance.
- Separate the test area/object with entry barriers, chains or warning signs/lights, in particular for HV tests. A working clearance of min. 1.5 m needs to be observed. Prior to any test, visually check again that nobody is still working on the test object or associated operating infrastructure.
- HV/LV test voltage shall never see any accidental leakage path to ground via other equipment. Isolate the intended test circuit from other electrical circuits, e.g. adjacent magnets, instrumentation cables or other test equipment.
- Unused open wires, cables, test leads connected to a test object are not acceptable – remove where possible or insulate appropriately prior to testing.
- Do not touch the test object, test equipment (except control panel) and in particular the test leads while a HV/LV test is in progress.
- Test objects and even test leads behave like a capacitor storing electrical energy if charged with DC high voltage. Usually the indicated HV/LV test equipment will safely discharge the test setup after each test run. If for any reason this fails (e.g. equipment error, test lead accidentally disconnected), be aware of possible electrical discharge to your body while approaching or touching conducting parts of the circuit. Keep the distance and carefully discharge the object manually.
- An inductive circuit, e.g. a magnet coil stores electrical energy if charged with DC current. It will create considerable high voltage if the current accidentally is interrupted. In case of SIS100 DPM/MDM the inductance of single objects and test currents are at a non-dangerous level. Moreover, coil excitation usually is not in the scope of EI-testing.

4. Test data records and protocols

Details like operator name, date/time, test conditions, safety measures, test setup, process data and test results shall be documented in a dedicated test protocol. **Modify the protocol correspondingly to the specific test needs** and summarize all tests briefly on a cover page.

Electrical Integrity - SIS100 Dipole Module @ Beamline					
Test Title:	**HV Insulation Test**				
Test Object:	SIS100 Dipole DO		CID: xx-yy-zzz-#	Nomenclature: 1S40xyz	
Responsible:	Max Mustermann SCM				
Location:	K0923A.U30.xxx	Date:	2025-Jan-01	Time:	12:34
Test Conditions					
Ambient Temp:.	20° C	Humidity:	50% rel.	Used Device:	Amprobe
Object Conditions					
Object Temp.:	293 K	Pressure:	atmospheric	Object Status:	
Object preparation:	Visual inspection, 2 days acclimatisation, dried with warm air, purged with nitrogen				
Specialty:	Test after tunnel insertion / repair of something				
Safety Measures:	Grounding/PE of vessel, object discharged, safety chains, lights				
Test Equipment					
Type:	Megger S1-568	Serial No.:	12345	Calibration Date:	2024-xx-yy
Test Procedure:	600 V - 60 s + 1500 V - 60 s + 2000 V - 120 s				
Test Setup & Connections:	Step voltage test; PLUS on bus-bar, MINUS on vessel/ground/PE, all other circuits and instrumentation to ground/PE				
Test Data					
Acceptance Criterion:	IR ≥ 1 GOhm @ all test steps				Passed/Fail:
Test Result:	DPo: 600 MΩ				FAIL
	DPi: 700 MΩ				FAIL
Add lines for each BB	QDo, QDi, F1o, F1i, F2o, F2i				
Remarks:	Reason probably xyz; proposal abc; NCR report #### send to WPL Test data stored under filename at \\campus\groups\testxyz\abc\filename				

Table 2: Exemplary test protocol template

Raw data, diagrams or dedicated test protocols generated by any specific test equipment shall be recorded and saved with all other test results. Before considering a test as failed, always **check the physical plausibility of test results** in order to validate the test setup was correct.

5. High Voltage Insulation Tests

DC-High-Voltage (HV) is required to test the insulation integrity of a dipole coil or rather the bus-bars in a dipole module including all instrumentation connected to this electrical circuit under test (“live circuit”). Depending on the type of dipole module called “**DI or DO**”, the coil is part of the **DPi or DPo** bus-bar. The MDM is providing the bus-bar system only, without coil.

The test voltage shall successively be applied to the eight bus-bars (**DPi/o, QDi/o, F1i/o, F2i/o**) inside a SIS100 DPM/MDM with reference to ground/PE in three consecutive steps (**SV - step voltage test**), while all other instrumentation and bus-bar sections in the module are grounded. Instrumentation might be attached conductive (e.g. voltage taps - VT) or insulated (e.g. sensors) to a bus-bar circuit. Therefore, voltage taps on the “live circuit” under test are excluded from grounding.

In case of doubt about the insulation status or visible damage at a test object, e.g. bended bus-bars, execute a resistance measurement to ground/PE on the circuit to be tested using a standard DMM (MΩ range) before starting any HV insulation test.

Prior to any HV-testing, allow test objects to get sufficient time for acclimatisation at the final test location, in particular after transportation. Humidity around the test area is a key factor for meaningful HV test results and should be considered carefully. Occasionally, drying of the test object with warm air (e.g. polyimide-wrapped parts, superinsulation, G10-brackets) is required as well as purging and cleaning the interior (helium tubes, pipes, voltage breakers) with nitrogen gas or dry air. Moreover, surface cleaning of voltage breakers from residues using isopropanol is recommended. Consider a certain flash-off time before starting a test.

Test objects might arrive sealed with a protective atmosphere (usually nitrogen gas) inside. Be sure about the test object content and pressure conditions with regard to possible electrical conductivity.

Acceptance criterion $\mathbf{R_{ins}}$: insulation resistance, referring to ground/PE

Ref.	Object	Test Voltage / Duration	Acceptance Criterion R_{ins} @ 293 K	Remarks
1	SIS100 DPM / MDM **Bus-bar**	**SV: 600 V** @ 60 s & **1500 V** @ 60 s & **2000 V** @ 120 s	≥ 1 GΩ	Insulation to ground & other electr. circuits

Table 3: HV-test acceptance criterion for stand-alone SIS100 DPM/MDM

6. Low Voltage Insulation Test

The DC-Low-Voltage (LV) test shall verify electrical insulation integrity of all instrumentation (sensors, thermocouples, heater elements). A single sensor/heater shall be electrically insulated with respect to ground/PE and to other electrical circuits, in particular adjacent devices attached to the same connector at the instrumentation flange.

The test voltage shall be applied to the instrumentation circuit under test with reference to ground/PE for a duration of 60 seconds, while all other instrumentation and bus-bar circuits in the dipole module are grounded. In general, the same environmental constraints, test conditions and safety measures apply as already stated for DC-HV-tests.

The cryo-heater cartridge comprises a **heater** element and a **thermocouple** (**TC**) in one housing, both to be tested at different voltages. Consider humidity as a limiting factor for this cartridge. This usually improves significantly at operation under vacuum conditions.

Ref.	Object	Test Voltage / Duration	Acceptance Criterion R_{ins} @ 293 K	Remarks
1	SIS100 DPM / MDM **Sensor & TC @ heater cartridge**	**50 V** @ 60 s	≥ 100 MΩ (**sensor**) ≥ 5 MΩ (**TC**)	insulation to ground & other electr. circuits
2	SIS100 DPM **Cryo Heater Element**	**100 V** @ 60 s	≥ 5 MΩ	insulation to ground limited due to strong hygroscopic behaviour

Table 4: LV-test acceptance criteria for stand-alone SIS100 DPM/MDM

7. Electrical Continuity Test

The electrical continuity test shall verify the presence and correct installation order of voltage taps (VT) along the magnet electrical circuit. VTs are part of the “Quench Detection System” applied for all sc-components. Electrical continuity shall be tested after transportation of a module or following a HV/LV test, to ensure there was no severe mechanical or electrical impact on any voltage tap.

The SIS100 DPM provides two interfaces at its instrumentation flange (IF) for continuity test (@ MDM, interface SDB only is available):

- dipole coil is connected to a 7-pin Fischer socket – **SDM**
- bus-bar circuits are connected to an 8-pin Fischer socket - **SDB**

In addition, **direct access** to the bus-bars is given at the **interconnection area** of modules.

An electrical circuit diagram of the test object and a good knowledge of the test procedure is required to evaluate test results. As there are two types of dipole modules – DI & DO and the MDM, three different schematics need to be considered.

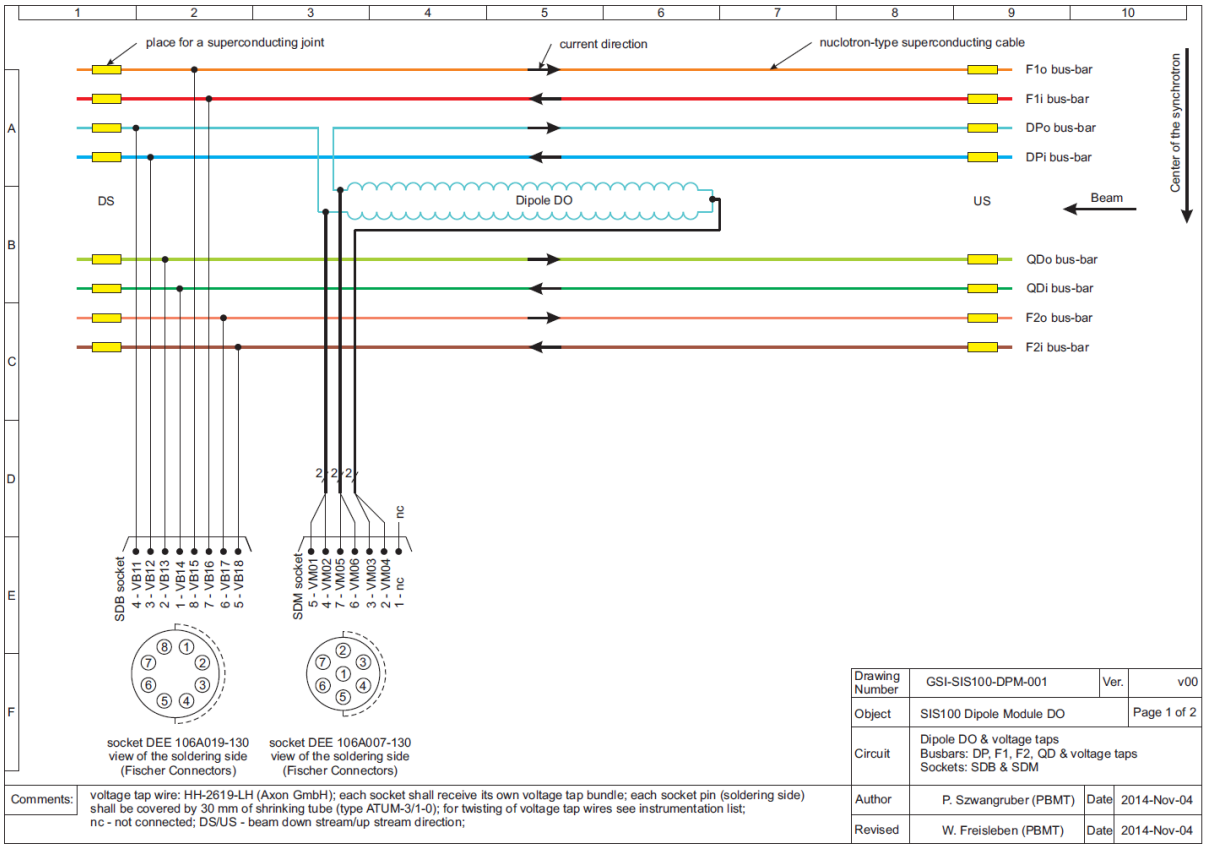


Figure 2: Exemplary circuit diagram of the SIS100-DO dipole module

For continuity testing on SIS100 dipole modules at the beamline, the **“Fast Continuity Test”** using the “**2-wire method**” shall be applied, i.e. measurement of electrical resistance along the respective circuit with respect to a reference voltage tap or directly to bus-bars using a digital multimeter (DMM). This is sufficient to verify the presence of voltage taps. The correct

VT installation order already has been verified at SAT of the component. In case of doubt crosscheck latest SAT protocol or apply advanced testing, e.g. voltage/current (V/I) method.

Electrical continuity acceptance criteria is presented in the following tables. **R_c** is the measured electrical circuit resistance. The test reference is defined as **VB11/VB12** (DO/DI type) for the coil respectively direct connection to corresponding bus-bars using long test leads.

SIS100 Dipole & Missing Dipole Module Bus-Bars			
VT#	**SDB Pin #**	**R_c / Ω**	**Remarks**
VB11	4	≤ 1	referring to DPo
VB12	3	≤ 1	referring to DPi
VB13	2	≤ 1	referring to QDo
VB14	1	≤ 1	referring to QDi
VB15	8	≤ 1	referring to F1o
VB16	7	≤ 1	referring to F1i
VB17	6	≤ 1	referring to F2o
VB18	5	≤ 1	referring to F2i

Table 5: Electrical continuity acceptance criteria @ SDB socket

SIS100 Dipole Module Coil			
VT#	**SDM Pin #**	**R_c / Ω**	**Remarks**
VM01	5	≤ 1	coil current input - plus
VM02	4	≤ 1	coil current input - plus
VM03	3	≤ 1	coil centre tap
VM04	2	≤ 1	coil centre tap
VM05	7	≤ 1	coil current output - minus
VM06	6	≤ 1	coil current output - minus
n.c.	1	∞	not connected
VB11 or VB12 @ SDB			**REFERENCE**

Table 6: Electrical continuity acceptance criteria @ SDM socket

8. Sensor Alive Test

The sensor alive test is performed on all temperature sensors and other instrumentation (heaters), installed within a SIS100 dipole module at the magnet yoke, the helium supply tubes and the vacuum chamber. The objective is to verify the presence and functionality of all instrumentation at given test conditions. Sensors resistance values shall be compared in line with their calibration curve values at the actual test object temperature to verify the acceptance limits.

The "**4-wire method**" shall be applied for testing of temperature sensors. Two wires are used for insertion of a test current into the test object and two other wires are used for measuring the resulting voltage drop across the object. This requires a DMM with a dedicated high impedance 4-wire sensor input and adjustable test current. Moreover, a polarity indicator is helpful.

An exception are thermocouples build into the cryo heater cartridges. The heater element shall be tested using the (less precise) "**2-wire method**". The thermocouple shall be connected to a DMM providing direct temperature reading functionality for type K devices.

IF: Instrumentation Flange
R_i: typ. instrumentation resistance @ 293 K (incl. wiring resistance if 2-wire method is used)
T_i: temperature value determined from individual sensor calibration curve; consider **effective ambient temperature** at the test object
T_{tc}: temperature indicated by thermocouple Type K @ direct readout on suitable DMM

SIS100 Dipole Module - Instrumentation @ 293 K					
Sensor	**Type**	**IF-Socket # : Pin**	**R_i / Ω**	**T_i , T_{tc} / K**	**Acceptance Criteria**
TV01	CCS/C2	#2: 1-2-3-4	800-1150	293 ±4.2	T_i @ calibration curve
TV02	CCS/C2	#1: 1-2-3-4	800-1150	293 ±4.2	T_i @ calibration curve
TV03	CCS/C2	#1: 5-6-7-8	800-1150	293 ±4.2	T_i @ calibration curve
TY01	CX-1050-SD-1.4L	#1: 9-10-11-12	47-106	293 ±3	T_i @ calibration curve
TY02	CX-1050-SD-1.4L	#3: 1-2-3-4	47-106	293 ±3	T_i @ calibration curve
TY03	CX-1050-SD-1.4L	#3: 5-6-7-8	47-106	293 ±3	T_i @ calibration curve
TY04	CX-1050-SD-1.4L	#1: 13-14-15-16	47-106	293 ±3	T_i @ calibration curve
TY04a	CX-1050-SD-1.4L	#2: 5-6-7-8	47-106	293 ±3	T_i @ calibration curve
TM01	CX-1050-SD-1.4L	#3: 9-10-11-12	47-106	293 ±3	T_i @ calibration curve
TL01	Thermocouple **Type K**, integrated @ HL01	#2: 11-12	17-30	293 ±3	T_{tc} @ DMM readout
TL02	Thermocouple **Type K**, integrated @ HL02	#2: 15-16	17-30	293 ±3	T_{tc} @ DMM readout
HL01	Cryo Heater 21W/43V	#4: 1-2	92 ±10	-	R_i @ 2-wire method
HL02	Cryo Heater 21W/43V	#4: 3-4	92 ±10	-	R_i @ 2-wire method

Table 7: SIS100 DPM instrumentation acceptance criteria

SIS100 Missing Dipole Module - Instrumentation @ 293K					
Sensor	**Type**	**IF-Socket # : Pin**	**R_i / Ω**	**T_i / K**	**Acceptance Criteria**
TV01	CCS/C2	#1: 1-2-3-4	800-1150	293 ±4.2	T_i @ calibration curve
TV02	CCS/C2	#1: 5-6-7-8	800-1150	293 ±4.2	T_i @ calibration curve
TV03	CCS/C2	#2: 1-2-3-4	800-1150	293 ±4.2	T_i @ calibration curve
TY01	CX-1050-SD-1.4L	#1: 9-10-11-12	47-106	293 ±3	T_i @ calibration curve
TY02	CX-1050-SD-1.4L	#2: 5-6-7-8	47-106	293 ±3	T_i @ calibration curve
TY03	CX-1050-SD-1.4L	#1: 13-14-15-16	47-106	293 ±3	T_i @ calibration curve
TY03a	CX-1050-SD-1.4L	#2: 9-10-11-12	47-106	293 ±3	T_i @ calibration curve

Table 8: SIS100 MDM instrumentation acceptance criteria

9. Electrical Integrity Tests at DPM/MDM in Pairs

The completion of SIS100 main magnet circuits will start with electrical and hydraulic connection of dipole modules in pairs, i.e. two SIS100 dipole modules in series. After initial alignment of the objects, amongst others supply tubes have to be connected, sc-joints have to be soldered at the bus-bar pairs and mechanical stabilization provisions shall be inserted within the space-limited “interconnection area” between modules. This severe intervention generates a risk of damage to the instrumentation (sensors and VTs) of modules or may decrease the overall electrical insulation significantly.

Therefore, a basic EI-test sequence following the interconnection process of two modules is required.

Seq.	Electrical Inspection on **DPM/MDM Pairs** @ ambient temperature (~ 293 K)	**Remarks**
1	Visual inspection of electrical installation	sc-joints & VTs, bus-bar area, wiring & sensors etc.
2	sc-joints quality and continuity	**EI-test method not defined yet;** implementation & QA acc. to instruction F-AA-SCM-en_MT0006; https://edms.cern.ch/document/3203584/2
3	HV-insulation test @ **combined modules**	SV - step voltage test up to **1500 V**; check plausibility with regard to stand-alone module results
4	Low voltage (LV) test on sensors & heaters @ **each module**	heater cartridges: heater unit @ 100 V & TC @ 50 V
5	Fast continuity test after HV @ **each module**	2-wire method
6	Sensor alive test after HV @ **each module**	consider temperature deviation from reference 293 K
7	Approval for further installation	next step: connection to adjacent modules

Table 9: EI-test sequence at two combined SIS100 DPM/MDM

This is a preliminary proposal. Inclusion of installation and test experience from string test is highly recommended. Reduction of test time, e.g. by combining bus-bars at HV-test or skipping tests may be discussed.

Considering two electrically connected objects at the interconnection area, a new EI-challenge is introduced: **quality inspection and electrical continuity of sc-joints** on all bus-bars. To date, a dedicated and efficient test method suitable at the beamline **is not available**. There can be a standard DMM resistance measurement, which has no meaning regarding the acceptance (≤ 2 nΩ) for operation at nominal magnet current. So far, we just rely on the workmanship of our joint soldering experts, best practice and proven materials. Test experience confirms, that acceptable joint continuity always was proven by 4-wire measurements at high current on the magnet test bench. Presently, as an alternative just a much more complex X-ray examination could be suggested.

LV, continuity and sensor alive tests shall be performed as described in the previous sections. The HV-insulation test of two or more combined units requires a more **extensive cable preparation** for grounding of all instrumentation and remaining bus-bar circuits during test. Moreover, **safety area and barriers need to be extended**, visual area control gets reduced the more units are involved.

The total **HV insulation resistance of combined modules** might be derived from string test results and further test experience at the beamline. Typically, a stand-alone SIS100 dipole module shows a much better value above its acceptance criterion $R_{ins} \geq 1$ GΩ. Anyway, if worst case all involved modules would touch this limit, the acceptance criterion for two combined modules reduces to $R_{ins@2} \geq 500$ MΩ (linear approximation not necessarily perfect choice).

This also means, we cannot distinguish anymore, if due to an intervention one of the combined modules significantly decreased its insulation performance **below** the **stand-alone** acceptance **criterion** limit (i.e. non-conformity) and the other one just is much better. Therefore, a rough **calculation of expected total resistance** using up-to-date HV-test results of the stand-alone modules might be indicated for comparison. Again: humidity might interfere with any meaningful result or calculation.

Ref.	Object	Test Voltage / Duration	Acceptance Criterion $R_{ins@2}$ @ 293 K	Remarks
1	DPM/MDM Pairs **Bus-bars**	**SV: 600 V** @ 60 s & **1000 V** @ 60s & **1500 V** @ 120 s	≥ 500 MΩ	validate R_{ins} with stand-alone object results

Table 10: HV-test acceptance criterion for two combined SIS100 DPM/MDM

10. SIS100 Main Dipole Circuit Considerations

In principle, the HV insulation resistance criterion of combined modules or a complete magnet circuit roughly is a function of the number (**n**) of electrically connected single objects:

R_{ins} ≥ 1 GΩ / n, i.e. ten accepted objects worst case would lead to R_{ins} ≥ 100 MΩ.

This assumes the standard HV test procedure at the beamline, considering a single bus-bar **open** circuit of **n** elements connected in series without connection to other circuits. Regarding the **HV test voltage applied to more than two objects**, a max. of **1 kV** is suggested.

Concerning the SIS100 accelerator **main dipole circuit** consisting of 108 DPM and 12 MDM, we need to consider the return bus-bar in each module which closes the circuit to the DP power converter. These previously were treated separately at SAT HV-tests, but now contribute to the total insulation resistance of the closed circuit to ground. Moreover, 6 bypass-lines (BPL), 3 feed-in-lines (FIL), 3 current lead boxes (CLB), 12 main current leads (MCL, possibly including 4 water cables plus power switches) and all dipole bus-bars within 83 quadrupole modules are not yet considered. If all these objects would touch the limit (1 GΩ), the **worst case** SIS100 dipole circuit insulation resistance to ground $\mathbf{R_{DPc}}$ might be:

$$R_{DPc} \geq \frac{1\ \mathrm{G\Omega}}{(108 + 12 + 6 + 3 + 3 + 83) * 2 + 12}$$, i.e. the acceptance criterion reduces to: $\mathbf{R_{DPc}}$ ≥ 2.2 MΩ.

The DP power converters in full operation might see a peak **leakage current to ground** of approximately 420 V / 2 MΩ = 210 µA. A much higher leakage current contribution in the **40 mA**-range will be present during ramping of dipoles due to parasitic capacitance to ground of voltage taps and associated QuD-cables.

11. Related Documents

[1] DGUV-V4 “Elektrische Anlagen und Betriebsmittel” (incl. Durchführungsanweisungen)

[2] DGUV Information 203-001 “Sicherheit bei Arbeiten an elektrischen Anlagen”

[3] DGUV Information 203-002 “Elektrofachkräfte“

[4] DGUV 203-034 Information “Errichten und Betreiben von elektrischen Prüfanlagen“