GSI FAIR	Technical Guideline	Number	01e
PB-MT	DC High Voltage Insulation Tests for SC Magnets	Status	2013-11-27

Contents

1. Scope 2
1.1. Limitations 2
2. Definitions 2
3. General Requirements and Information 7
3.1. Concept Overview 7
3.2. General Requirements 8
3.3. Required Documentation 8
3.4. Required Equipment 9
4. DC High Voltage Test Performance 9
4.1. Safety Precautions 9
4.2. Conditions of High Voltage Application 10
4.3. Test Voltage (V_{test}) 11
4.4. Test Duration (t_{test}) 12
4.5. Step Voltage Implementation for DC HV Test 13
4.6. Acceptance Criteria 15
4.7. Minimum Resistance Acceptance Criteria 16
4.8. Additional Test Results Processing and Actions 17
4.9. DC Insulation Test of Temperature Sensors 20
4.10. The List of DC HV Tests of completed SC Magnet 21
4.11. The List of DC HV Tests of Nuclotorn Cable with Insulated Strands 22
5. Dedicated Tests 23
5.1. General requirements for Dedicated Tests 23
5.2. Common Requirements for Samples 24
5.3. Nuclotron type End Coil Samples and related HV Tests 25
5.4. Nuclotron type End Coil Sample with Insulated Strands and related HV Tests 27
5.5. Dummy Coil and/or Test Coil and related HV Tests 28
5.6. Dedicated Dummy/Test Coil Test Program 29
6. Extended Test Programs 31
6.1. First of Series SC Coil Production 31
6.2. First of Series SC Unit/SC Module Production 31
6.3. First of Series SC Unit/SC Module Testing at Cold/Cryogenic Condition 32
6.4. The beginning of the Series Production 33
7. Standard Test Programs for Series Production 34
7.1. DC HV Insulation Test of the SIS100 SC Coil and Bus-Bars Production 34
7.2. DC HV Insulation Test of the SIS100 SC Magnet Production 36
7.3. DC HV Insulation Test of the SIS100 SC Dipole Module Production 37
7.4. DC HV Insulation Test of the SIS100 SC Quarupole Unit and Doublet Module Production 38
7.5. The Test Program for Cold Testing (Nominal Condition) of Series Production 39
8. Test Record 41
8.1. Standard Informational Contents of the Test Record 41
8.2. Measurement Conditions Documented in the Test Record 41
8.3. DC High Voltage Insulation Test Record Requirements 42
8.4. Test Results Evaluation 42
9. Data Management 43
10. References 43

1. Scope

I. This document defines requirements and tests to be executed for the acceptance of the electrical insulation of the SIS100 Nuclotron type magnets (coil and bus-bars) at warm and cold/cryogenic conditions.

II. This document defines requirements and tests to be executed for the acceptance of the electrical insulation of a temperature sensor circuit (see section 4.9).

III. This document can be the basis for DC High Voltage Insulation tests of other accelerator components after providing appropriate safety precautions and other required adaptations.

1.1. Limitations

I. The Standard Test Programs and Acceptance Criteria described in this Technical Guideline are based on the limited experience with testing of the SIS 100 dipoles prototypes and FoS dipole coil. After gaining more experience with testing (e.g. a Dummy/Test Coil) further modification will be performed.

II. This document does NOT have any other purpose than mentioned above.

III. This document is NOT relevant to the DC High Voltage Insulation Tests of the Superconducting Accelerator.

2. Definitions

I. Definition of terms used in this Technical Guideline are presented in following groups:

A. General Terms and Objects Definitions - Table 1

B. Definition of Conditions - Table 2

C. Data Management and Quality Assurance Definitions - Table 3

D. Testing Equipment and Test Performance Definitions - Table 4

Table 1 General Terms and Objects Definitions

Term	Definitions and Abbreviations
Customer	GSI or FAIR
Contractor	a company which performs the required tests during production or testing at cold conditions based on the contract with the Customer.
Technical Guideline	**TG**
Superconducting cable (SC cable)	a cable made from superconducting material (strands) and other required components; in current version of TG only Nuclotron type is considered
Superconducting coil (SC coil)	a coil wound with of SC cable; SC coil consists of coil itself and coil bus-bar
Superconducting unit (SC unit)	consists of one or more SC magnet with the related systems/devices, already installed; in current version of TG the SC Unit is the Quadupole Unit which consists of a quadrupole magnet and its own bus bar pair, and other devices directly connected to the quadrupole (e.g. corrector magnets and related circuits)
Superconducting module (SC module)	consists of one or more SC magnet inserted into cryostat. Examples of SC modules are SIS100 Dipole (consists of 1 SC unit with 1 SC magnet) and SIS100 Quadrupole Doublet (consists of 2 SC units with 2 SC magnets and a few correctors)
bus-bar or separate bus-bar or return bus-bar	the SC cable which goes through the SC Unit / SC Module, but is not electrically connected to the SC coil.
independent circuits	are electrical circuits which have no electrical connection between each other (e.g. SC coil and related voltage taps or bus-bar and related voltage tap)
cryostat	a technical system enclosing another technical system to be operated at cryogenic temperature (e.g. 4.5K).
voltage tap	an insulated wire (Cu alloy) connected to an appropriate part of the SC coil or bus-bar (for quench detection purpose) on one side and to a connector/socket on the other side. The connector/socket is installed on the cryostat (on dedicated flange) and it is accessible from outside of the SC unit or SC Module.
Baking Mold	a metallic construction which is in touch with the coil; a coil after winding is inserted to the Baking Mold for the baking; during baking process a force is applied on Baking Mold; a coil is completely surrounded by the metallic construction of a Baking Mold
Nuclotron type End Coil Sample	a sample is build of the Dummy Cable or the SC Cable; it consist of several cables (which are not electrically connected together) and which are placed in the same manner like the winding cables; the shape is similar to the coil end (coil head) which suppose to be the most complicated part of the coil (bending radius)

Dummy Cable	is the cable made of the non-SC components (like copper) with the same geometrical parameters (size, shape) and electrical properties (type of electrical insulation) and made according to the technology used for SC Cable
Dummy Coil	the coil made of Dummy Cable with the same geometrical parameters (size, shape) and electrical properties (type of electrical insulation) and made according to the technology used for FoS Coil; the construction of Dummy Coil is modified in a way that artificial electrical insulation weakness and failures can be introduce purposefully for dedicated tests.
Test Coil	the coil is similar to the FoS or/and Series Coils; the coil is made of SC Cable or in exception of Dummy Cable. The Test Coil is subjected to dedicated tests program until the electrical integrity is degraded /broken. In some cases electrical failures may be introduced purposely to simulate electrical problems. For DC HV tests the Dummy Coil is sufficient; for Capacitor discharge and others the Test Coil is required.
First of Series Coil (FoS)	is the first coil made of SC cable; this coil is tested with the extended testing program. In case that first coil does not pass all required tests the second coil has to be build; the FoS Coil has more instrumentation and temperature sensors installed for acceptance tests than a SC Coil for series production; the term FoS is used until a coil fully complies with the specification and passes all required tests successfully; the final FoS shall be the same like SC Coil for series production
temperature sensor	the object with 4 wires (in special case may be 3 wires) which is used for temperature measurement; there are tree types of the temperature sensor: CERNOX, CLTS and PT100.

Table 2 Definition of Conditions and States

Term	Definition
warm condition	the ambient (room) condition
cold condition or cryogenic condition	a condition under which the material becomes superconducting and can be operated (nominal current) under these conditions (e.g. 4.5K)
quench	the transient of a superconductor from the superconducting state to the normal conducting state

Table 3 Data Management and Quality Assurance Definitions

Term	Definition
Travel Book	a folder containing all relevant information, documentations and test records in a printed/written form; the Travel Book travels with the object and it consist of all documentation related to the object to which it is attached.
electronic documentation	a set of electronic files which contain the same information as the travel book and which are delivered in a manner (e.g. CD or/and email or/and upload into data base) which was accepted by the Customer; pdf format is recommended
test record	a document in which all information related to test performance, test results and test evaluation are included; other used name is protocol
raw data	the direct results of measurements performed using the testing equipment without any modification (e.g. recalculation or scaling); In case recalculation or/and scaling factors are required all related information have to be delivered with the raw data.
recording	recording and storing of the measured values with the sampling rate at least 1Hz or higher frequency (e.g. kHz).
file with raw data	an electronic file with all measured and recorded data in it; the obligatory format is the ASCII file prepared using the accepted template; additionally other data format can be requested by the Customer
Technical or Detailed Specification	is the documentation containing the functional or detailed technical data and the information which is a part of the contract.
Non-Conformity NCR	the Non-Conformity in terms of this TG should be created in one of following situations: 1. when the test results do not comply with the Acceptance Criteria 2. when the test can not be performed according to the TG

Table 4 Testing Equipment and Test Performance Definitions

Term	Definition
High Voltage Tester (HV Tester)	a device which can provide the required voltage and current, and has the possibility for displaying and/or recording the voltage and the current; the HV Tester has three terminals: **plus**, **minus** and **guard (**Fig. 1**)**; the HV Tester has the ability to calculate the insulation resistance of the measured object.
guard terminal	the terminal of HV Tester used for elimination of stray leakage current (mainly surface leakage current) from total leakage current measured by HV Tester (see User Guideline of HV Tester)
standard test or the test with the positive polarity	when the positive pole (plus) of the High Voltage Tester is connected to a non-insulated (conductive) part of the SC coil and the negative pole (minus) of the High Voltage Tester is connected to the ground (wound foil, Baking Mold, yoke or cryostat)
negative polarity	when the negative pole (minus) of the High Voltage Tester is connected to a non-insulated (conductive) part of the SC coil and the positive pole (plus) of the High Voltage Tester is connected to the foil (artificial ground) or the Baking Mold or the yoke (cryostat).
both polarities test	consists of the test with the positive polarity and the test with the negative polarity
DC High Voltage	has the same meaning as the **High Direct Voltage** (recommended by IEEE)

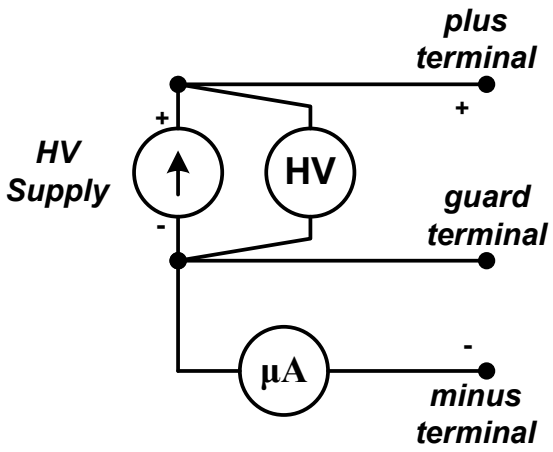


Fig. 1. Scheme of High Voltage Tester with three terminals

3. General Requirements and Information

3.1. Concept Overview

I. At the time of writing this version of the Technical Guideline (TG), the experience with DC High Voltage Insulation tests is limited to several objects (SC magnets).

II. To improve on from the existing situation, dedicated components and tests are required:

   A. the Nuclotron type End Coil Sample – to derive adequate testing parameters.

   B. a Dummy Coil – to prove the testing procedure and acceptance criteria for DC HV test at warm,

   C. a Test Coil - to prove the testing procedure and the acceptance criteria for DC HV Capacitor Discharge tests at warm and at cold condition

   Dedicated Tests shall be discussed and accepted during last design review and reflect the state of knowledge at the time of a review.

III. Based on results of Dedicated Tests the Extended Test Program for FoS Coil shall be derived.

IV. Based on results of the Extended Test Program, the Standard Test Program for series production shall be modified after finalisation the FoS Coil tests. The Standard Test Program shall comply with test programs presented in this TG. Fig. 2 presents the relationship between different types of testing programs.

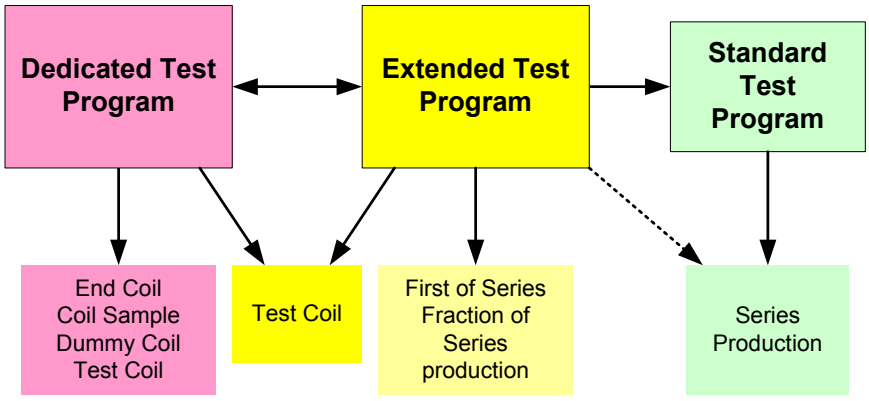


Fig. 2. Relationship between the Dedicated, Extended and Standard Test Programs

3.2. General Requirements

I. All described checks and tests have to be performed in accordance with the requirements described in this TG and they have to be documented in accordance with the requirements described in this TG using templates (printed/written, electronic form and raw data files) which the Customer accepted.
II. Written/printed forms of the tests records and documentation have to be attached to the Travel Book.
III. The test record shall present the comprehensible structure and the contents documenting every test executed.
IV. An electronic form (e.g. .pdf or .doc format) of the tests records and documentation have to be delivered to the Customer in the way the Customer accepted (e.g. CD or/and email or/and upload into data base).
V. The recordings of the measured values are mandatory; the measured values have to be delivered as a file with raw data (templates have to be accepted by the Customer) with the ASCII format and other formats the Customer accepted.

3.3. Required Documentation

I. A test record should contain at least the information defined in chapter 8 of this TG.
II. Each test record has to indicate whether the Acceptance Criteria have been fulfilled. If not, the test record shall explain which ones were not fulfilled (e.g. measured leakage current is 10 µA, the acceptance criteria being less than 1 µA).
III. If the Acceptance Criteria is not fulfilled the Non-Conformity (NCR) shall be created with information which criteria were not fulfilled and related test record shall be attached to the NCR document.
IV. A copy of the calibration certificate of the testing equipment is required and it shall be included in the Travel Book and in the electronic documentation (e.g. High Voltage Tester calibration certificate).
V. Time-dependent measurements shall be recorded and should be attached as:
    A. diagrams, to be included in the test record (printed and electronic form),
    B. file with a raw data.

3.4. Required Equipment

I. The following equipment is required for the DC High voltage tests

A. High Voltage Tester has to fulfil the following conditions:

- minimum testing voltage is 3kV,
- the value of test voltage fluctuation should not exceed 0.1%
- recommended current is 1mA, it is mandatory that all HV testers used during testing have the same current limitation; it is recommended to use one type of HV Tester the Customer accepted,
- recommended accuracy:
  a. Resistance ± 5% of the measured value (for 1MΩ – 1TΩ at 1kV…3kV)
  b. Current ± 5% of the measured value ± 0.2nA (resolution at the lowest range 0.02nA)
  c. Voltage ± 2% of the measured value ± 1V
- cables and probes, which have to comply with safety standards,
- possibility to read and record the current and the voltage during the test (at least 1 measurement per second),
- tester shall be able to discharge the tested circuit after the test completion,
- valid calibration certificate,
- acceptance tests of the device, if calibration certificate is not achievable,
- safety test for electrical safety according to valid regulations (e.g. German BGV A3 certification).

B. Laptop, Personal Computer or other Controller for raw data recording.

4. DC High Voltage Test Performance

4.1. Safety Precautions

I. For any electrical test adequate and latest safety precautions have to be taken; see [1] and [2].

II. Due to using high voltage, the tests should be conducted only by the experienced personnel.

III. Safety measures for testing the magnet with high inductance or capacitance have to be applied and they have to be up to date. These measures are not described in this TG.

IV. If tests will take place on the GSI or FAIR facilities, German Safety Regulations according BGI 891 and BGI 519 have to be observed.

4.2. Conditions of High Voltage Application

I. Following circuits are considered as independent:
   A. a coil and related voltage-taps,
   B. a bus-bar and related voltage-tap,
   C. each cable in the Nuclotron type End Coil Sample,
   D. each insulated strand in the SIS100 Corrector and Low current Quadrupole coils (before joints soldering).

II. The electrical insulation test shall be performed between an independent circuit (the plus terminal of HV Tester) and the ground (the minus terminal of HV Tester); all independent circuits not under HV test have to be connected to the ground. This rule is applied for independent circuits which touch each other or which are placed in the same insulation structure (exception a cable with insulated strands see section 4.11).

III. The insulation tests shall be performed between an independent circuit and another independent circuit (e.g. a quadrupole versus a corrector, a bus-bar versus a magnet); all independent circuits not under HV test have to be connected to the guard terminal of HV Tester (exception a cable with insulated strands see section 4.11).

IV. The high voltage test must be performed on the coil at an ambient temperature above a dew point.

V. The high voltage test must not be performed on the coil with the temperature higher than 40^{o}C.

VI. The high voltage test at cold condition means the temperature of a coil is around 4K

VII. The coil terminals shall be short-circuited together (fixed connections) before high voltage test and they should stay connected together during and after high voltage tests.

VIII. The tested circuit shall be discharged before and after the test (short-circuited to the ground).

IX. The respective insulation tests must be performed in case of any changes and/or actions which can affect the quality of insulation integrity; at least after completion of each stage of the production and testing. Examples of changes and actions are listed below:
   A. changes of circuit configuration (e.g. connection/soldering/welding of bus-bar/ coil),
   B. changes of electrical instrumentation or connections (e.g. voltage taps connection/soldering, connection/reconnection of connectors),
   C. a cool-down or warm-up,
   D. powering with nominal current
   E. outdoor transportation (e.g. from one manufacturing site to another).

4.3. Test Voltage (V_{test})

I. The rule defining the test voltage (V_{test}) knowing the maximum voltage (V_m) during operation or quench is:

$$V_{test}=2*V_m \text{ for } 100 \leq V_m \leq 1500V , \quad (1)$$

and

$$V_{test}=200V \text{ for } V_m \leq 100\ V \quad (2)$$

Fig. 3 presents the V_{test} defined by equations mentioned above and the voltage for both polarities test (positive and negative polarity)

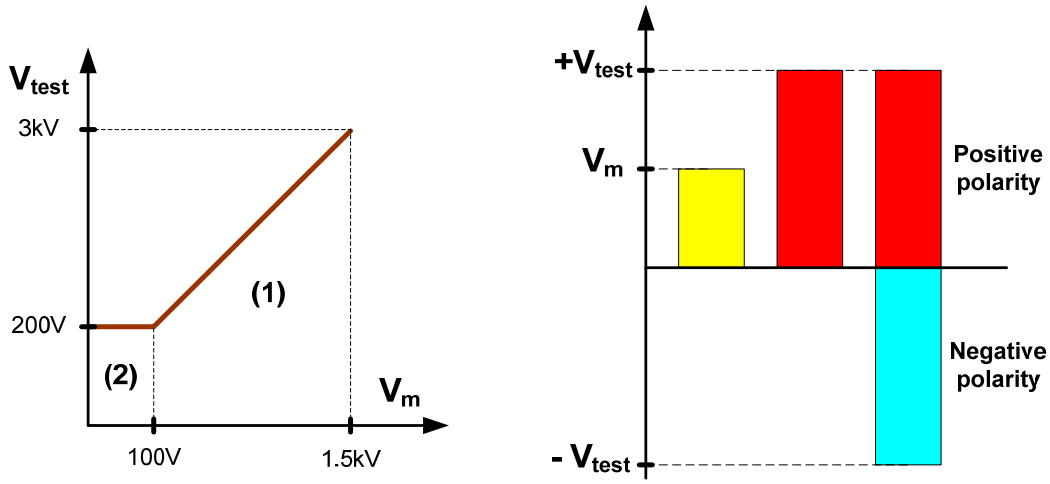


Fig. 3. Testing voltage (V_{test}) required by equations (1) and (2); and both polarities (positive and negative) tests

This rule is not applicable for testing the temperature sensors (see section 4.9) and for an independent circuits with a temperature sensor directly connected to it (see below).

II. A temperature sensor must not be placed on a non-insulated superconducting coil, bus bar, cable or conductor which is a part of a live electrical circuit. In case the temperature sensor is directly connected to the live circuit the required DC high voltage test shall be done before installing of the temperature sensor. The maximum testing voltage of a circuit with a temperature sensor directly installed (no additional insulation between live circuit and sensor housing) shall be below 250V (in case of CERNOX); please prove the value of the testing voltage according to the electrical insulation properties of the sensors and instrumentation wires itself. The maximum testing voltage of a circuit with a directly connected temperature sensor has to be accepted by the Customer.

III. After evaluation of the Dummy/Test Coil and FoS Coil the decision of using both polarities test for every applied voltages will be made by the Customer.

IV. The value of V_{test} of each independent circuits shall be given in the Detailed or Technical Specifications. Currently available V_{test} values are presented in the Table 5.

Table 5 Examples of the test voltages (coil vs. ground) used for testing of Nuclotron SC magnet

Magnet	$V_{test_before_baking}$	V_m	V_{test}
SIS100 Dipole	to be defined *	1500V	3000V
SIS100 Quadrupole	to be defined*	1500V	3000V
SIS100 Chromaticity Sextupole	to be defined**	defined by the detailed or technical specification	
SIS100 Steerer			
SIS100 Multipole Corrector			
SIS100 Low Current Quadrupole			

* The value has to be derived from the tests of Nuclotron type End Coil Samples before baking (see section 5.2).

** In case of SIS100 correctors there are different values of test voltages between the strands, between the strands and the tube, between the coil and the ground (yoke). Values have to be derived from the Samples before baking (see section 5.2).

4.4. Test Duration (t_{test})

I. The testing time should be long enough to last until the absorption/polarisation current becomes negligible. Based on experiments (with the Dummy/Test Coil and FoS Coil) the following times should be considered: t_{test} = {120s, 180s, 240s, 300s}.

II. The minimum test duration t_{test} shall be 120 seconds.

III. Any change of t_{test} has to be accepted by the Customer.

4.5. Step Voltage Implementation for DC HV Test

I. The requirements described in section 4.1 and 4.2 shall be observed.

II. The acceptance test shall be performed in a clean and dry surrounding where dust concentration is as low as possible.

III. The operator must ensure that the tested circuit is not charged before the test (short-circuited to the ground before test).

IV. All HV tester terminals (plus, minus and guard if requested) should be well connected to the object under test. The guard terminal shall be connected according to the description.

V. Tests should be carried out in 3 steps at least (each step lasting t_{test} = 120s for standard test, see Fig. 4):

- step A: $\mathbf{V_{testA}} = 0.2 * V_{test}$ (4)
- step B: $0.3 * V_{test} \leq \mathbf{V_{testB}} \leq 0.6 * V_{test}$ (5)
- step C: $\mathbf{V_{testC}} = V_{test}$ (6)

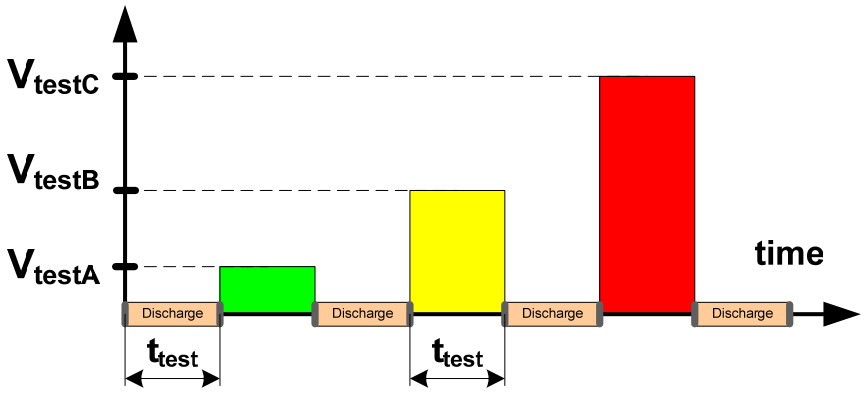


Fig. 4. Standard 3 voltage steps testing procedure

The currently defined steps of testing voltage for SIS100 Dipole and Quadrupole are presented in Table 6. For other magnets these steps shall be defined during the Final Design Review.

Table 6. Test voltages used for SIS100 Dipole and Quadrupole testing

Magnet	$V_{test_after_baking} = V_{test}$		
	V_{testA}	V_{testB}	$V_{testC}=V_{test}$
SIS100 Dipole	600V	1500V	3000V
SIS100 Quadrupole	600V	1500V	3000V

VI. In case that the HV Tester or HV testing system has a predefined automatic testing procedure call it 'Step Voltage' (e.g. 5 steps - Fig. 5), this procedure could be used instead of 3 steps tests presented above. It is recommended that the duration of each step is 120s. In case of 5 steps test the discharge time should be at least 240s.

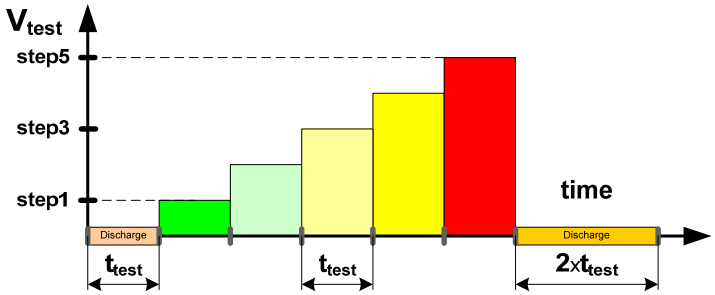


Fig. 5 Alternative 5-voltage steps testing procedure

VII. All steps of one polarity test shall be included in on test record.

VIII. In case that insulation resistance of the SC Coil vs. ground is below 100MΩ during the test, realization of the next step involving higher voltage should be carefully considered, reported and discussed with Customer before execution. The aim of the investigation is to find the reason (explanation) why the leakage current is so high. In this situation the Minimum Resistance Acceptance Criteria (see section 4.6) is not fulfilled. The NCR shall be created.

IX. The object after the test has to be discharged; the standard time of discharge should be at least equal to the time of the test (Fig. 4 and Fig. 6).

X. All DC High Voltage Insulation tests shall be recorded with the sampling rate at least 1Hz or higher. The recording of discharge current is recommended.

XI. The both polarities test (negative and positive) is required for the Samples, Dummy Coil, Test Coil and FoS Coil testing (Fig. 6). In case of test with the opposite polarity the double time for discharge is required; the discharge time should be verified by the experiments.

XII. The decision on performing both polarities test as the standard test for series production shall be taken after the Dummy Coil, Test Coil and FoS Coil tests are analysed

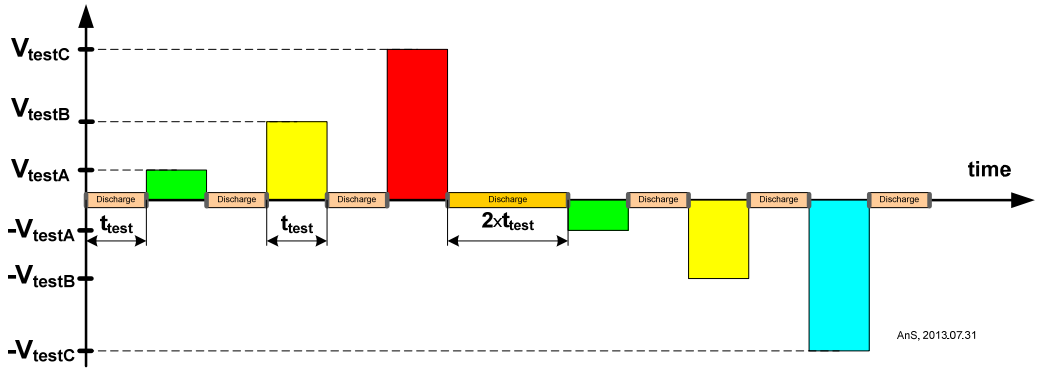


Fig. 6. Test sequence for the 3-steps of both polarities tests

4.6. Acceptance Criteria

I. The DC High Voltage Insulation Tests have to fulfil Acceptance Criteria listed below :

A. Minimum Resistance Acceptance Criteria

II. In case any of DC High Voltage Insulation test does not comply with Acceptance Criteria the Non-Conformity (NCR) has to be created and the object under test is rejected. The Non-Conformity has to be investigated by the Contractor and the report with conclusions has to be sent to the Customer as soon as possible. The Contractor shall propose a mitigation action.

III. When a test can not be performed according to the TG or/and according to the testing program requested by the Customer the Non-Conformity shall be created (this NCR has no influence on the object status). The Contractor must change the condition that the test can be performed according the TG and requested testing program.

IV. The Table 7 presents current status of Non-Conformity situations during DC high voltage test.

Table 7. Current status of Non-conformities during DC HV tests

	Non-Conformity (NCR)	Object Status
1	when the test results do not comply with the Acceptance Criteria	Rejected
2	when the test can not be performed according to the TG	No influence

4.7. Minimum Resistance Acceptance Criteria

I. The Minimum Resistance Acceptance Criteria must be fulfilled by the DC High Voltage Insulation test for:

A. a coil or bus-bar before baking (to be defined)

B. a stand alone coil or bus-bar (after baking, during and after assembly, not connected to a testing infrastructure before and after cold test) ≥ 20GΩ

C. a coil or bus-bar connected to the testing infrastructure at room and cryogenic temperature ≥ 1GΩ

II. If the Technical or Detailed Specification does not state differently, at the end of any t_{test} period (120 seconds is the default t_{test}) at constant test voltage (V_{test}), the electrical insulation resistance should be above R_{min}:

$$R_{test} \geq R_{min} \quad (7)$$

The minimum resistances for different stages of the coil production and testing are presented in Table 8 and are valid for any V_{test}. Presented values are based on tests of SIS100 prototypes and FoS Dipoles.

Table 8. Required Minimum Insulation Resistance of SC Coils and Bus-bars for different stages of the production and testing

	Minimum Insulation Resistance R_{min} at V_{test} and t_{test} of SC Coils and Bus-bars for different stages of the production and testing						
Status and condition description	Before baking	After baking	SC Magnet SC Unit SC Module assembly and testing	SC Unit SC Module connected to a testing infrastructure	SC Unit SC Module at Cold Test	SC Unit SC Module After warm-up	SC Unit SC Module After Cold Test and Disconnection
	in Baking Mold		stand alone inserted into yoke/cryostat	connected to a testing infrastructure			stand alone inserted into yoke/cryostat
	at room temperature		at room temperature		at cryogenic temperature	at room temperature	
'dry' coil technology SIS100 Dipole	proposed: ≥ 5GΩ**	≥ 20GΩ**	≥ 20GΩ***	≥ 1GΩ	≥ 1GΩ	≥ 1GΩ	≥ 20GΩ***
'wet' coil technology SIS 100 Quarupole	to be defined *	≥ 20GΩ**	≥ 20GΩ***	≥ 1GΩ	≥ 1GΩ	≥ 1GΩ	≥ 20GΩ***
'mixed' coil technology SIS100 Correctors	to be defined *	proposed: ≥ 20GΩ**	proposed: ≥ 20GΩ**	≥ 1GΩ	≥ 1GΩ	≥ 1GΩ	proposed: ≥ 20GΩ**

* The value has to be derived from the testing of the Nuclotron type End Coil Samples or the Coil Samples before baking and verified during the Dummy/Test Coil and/or the FoS Coil tests and be accepted by the Customer.

** The value shall be confirmed after Dummy and FoS Coils tests.

*** The value shall be verified after the FoS Coil tests.

III. For the evaluation process of the positive and negative polarities tests, the lower resistance / higher leakage current has to be taken into account; both polarities tests have to be recorded and the results have to be presented on the test record.

4.8. Additional Test Results Processing and Actions

I. Based on the knowledge available at the time of writing this TG, the following test results processing shall be done and included into the test record:

A. Processing of Step Voltage Tests
B. Analysis of Leakage Current Decay
C. Comparative Analysis of the Test Results for Similar Objects at Similar Testing Conditions
D. Comparative Analysis of the Test Results for the One Object at Similar Testing Condition

II. **Processing of Step Voltage Tests**

A. All different steps of Step Voltage Tests (see section 4.5) shall be presented in one test record
B. The change in insulation resistance R_{test} at t_{test}, between V_{testC} and V_{testA} whereas the ratio V_{testC} / V_{testA} is 5 should not exceed 0.25 [3]. The current recommendation and action for the Step Voltage test are presented in Table 9.
C. The value of R_{testC} / R_{testA} ratio shall be calculated and included into test record.

Table 9. Processing of Step Voltage Test

V_{testC} / V_{testA}	R_{testC} / R_{testA}	Action/ Recommendation
5	$1 > R_{testC} / R_{testA} \geq 0.75$	-
5	$0.75 > R_{testC} / R_{testA} \geq 0.5$	to check: 1. if object is not below a dew point 2. presence of moisture or other contaminant
5	$0.5 > R_{testC} / R_{testA} \geq 0.2$	to check as above and: 3. the object temperature
5	< 0.2	to check as above and: 4. pressure of insulation vacuum

D. In case that this R_{testC} / R_{testA} is below 0.2 the clear warning has to be put into test record. The investigation of the electrical insulation weakness has to be performed by the Contractor. The Contractor has to present conclusion and propose a mitigation action if it is necessary. The conclusion and proposal shall be agreed by the Customer. The Customer has right to propose its own solution.

III. **Analysis of the Leakage Current Decay**

A. The decay analysis shall only be applied for a test with the measured leakage current above 1nA and an insulation resistance below 500GΩ.

B. The analysis shall start from results of the highest test voltage (V_{testC}). If the highest test voltage (V_{testC}) fulfils criteria mentioned in point C (in this section), the investigation for lower test voltage is not required.

C. The evaluation criteria are following:

   a. The leakage current should decrease according to the following time response:

   $$I_{leak_MAX} > I_{leak}\ (30s) > I_{leak}\ (60s) > I_{leak}\ (120s)\ @\ \text{constant}\ V_{test}$$

   the time of the maximum leakage current depends on the HV tester features and on the object capacitance; the max leakage current should appear within first 10 seconds.

   b. The difference between the local minimum and maximum of the positive jump of the leakage current shall not be higher than 20% at the constant V_{test} .

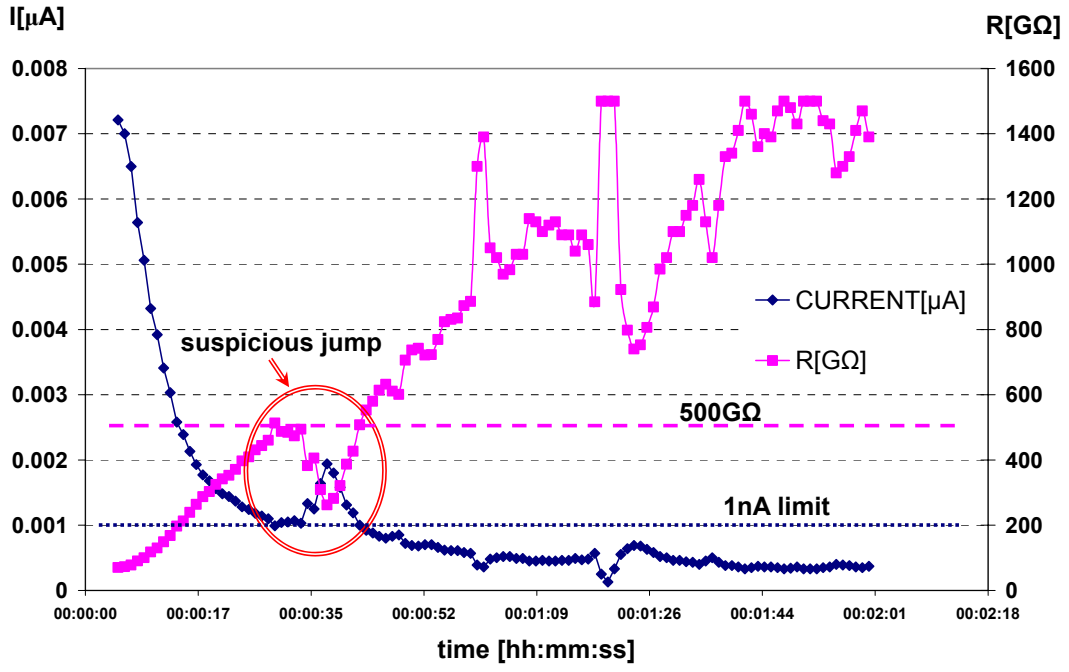


Fig. 7. Example of DC High Voltage Insulation test with positive leakage current jump; in presented case after increasing V_{test} by a factor of about 1.5 (in the next testing step) the break-down was observed

D. In case only the criteria mentioned in point C (in this section) are not fulfilled, following action shall be taken as the minimum:
   a. check if measured circuit is connected to the HV Tester,
   b. check for the presence of moisture or contamination,
   c. check properties/behaviour of the testing equipment/system,
   d. check the testing history of the object under the test,
   e. perform the test with higher voltages e.g. from $1.1*V_{test}$ up to $1.5*V_{test}$ if possible.

E. In case that the criteria mentioned in point C (in this section) are not fulfilled the clear warning has to be put into test record. The investigation of the electrical insulation weakness has to be performed by the Contractor. The Contractor has to present conclusion to the Customer.

F. The improvement of the Analysis of the Leakage Current Decay can be done after Samples, Dummy/Test Coil and FoS Coil tests are performed and analysed. At the moment of writing this TG it is assumed that the negative jumps/flickers of leakage current can be ignored.

IV. Comparative Analysis of the Test Results for the Similar Objects at Similar Testing Conditions

A. A data base or at least the files (e.g. excel type) shall be created and constantly updated, where all DC HV test results at $V_{test} = V_{testC}$ and t_{test} for similar objects and similar testing condition are stored. A statistical analysis shall be done.

B. A data base (or the set of files) should consist of the results of all standard DC HV tests required for production and testing phase.

C. As long there are no clear rules to recalculate the test results to the reference temperature and humidity there are no criteria for the evaluation.

D. The results from these files shall be used for quality inspection of the Contractor production process.

V. Comparative Analysis of the Test Results for One Object at Similar Testing Conditions

A. A data base or at least the files (e.g. excel type) shall be created and constantly updated, where all DC HV test results at $V_{test} = V_{testC}$ and t_{test} of the one object at similar testing condition are stored. A statistical analysis shall be done.

B. A data base (or the set of files) should consist of the results of all DC HV tests required of the one object at similar testing condition. The trend of leakage current (insulation resistance) shall be monitored over the production and testing at similar testing conditions.

C. In case the trend shows electrical insulation degradation, more than one order of magnitude (10% of one of previous values - excluding the humidity and temperature influence) between different stages at similar testing conditions, the Customer shall be informed within 24h and the Non-Conformity 'Unexpected Electrical Integrity Degradation Progress' shall be created. The Contractor shall make the analysis and propose the improvement measures.

4.9. DC Insulation Test of Temperature Sensors

I. The electrical insulation of temperature sensor circuits (temperature sensor and related instrumentation wires) has to be tested.

II. The test of electrical insulation only in DC mode (positive polarity) shall be done for:

A. A sensor and related to the sensor instrumentation wires vs. ground or vs. an object were the sensor is installed (the object must be connected to the ground).

III. A low voltage is applied for testing the electrical insulation of CERNOX and CLTS sensors. If there is no other statement in the sensor and wire specification the applied voltage shall be V_{testA} =20V(or25V) and V_{testC} = V_{test} =100V.

IV. The PT100 sensor can be constructed in the high voltage version, in that case the value of testing voltage can be higher, according to the specification; for other cases low voltage has to be applied (see point above)

V. The test duration t_{test} for temperature sensor circuits is 120s.

VI. Each sensor is connected to an individual socket (LEMO 4 pins). All four wires (pins) of the sensor have to be shorted together and connected to the plus terminal of High Voltage tester.

VII. The Acceptance Criterion for the Temperature Sensors insulation test is the following:

A. Insulation resistance of temperature sensor R_{TStest} at t_{test}=120s has to be higher than 100MΩ for both testing voltages ($\mathbf{V_{testA}}$ and $\mathbf{V_{testC}}$).

VIII. It is recommended to prove, before and after electrical insulation test, that all 4 wires of the temperature sensor and the temperature sensor itself are in operation (the reading of the sensor resistance should be inside the defined range of the temperature-resistance characteristics for the family of these sensors).

4.10. The List of DC HV Tests of completed SC Magnet

I. The Table 10 consists of DC High Voltage tests to be done on completed SC Magnet.

Table 10. The list of DC High Voltage Tests to be done on completed SC Magnet, SC Unit and SC Module, and HV Tester configuration for standard (positive polarity) test.

Test Code	**HV Tester terminals** (positive polarity test)		Remarks
used in this TG	**Plus**	**Minus**	
A	**Coil/Coils**	**Yoke/ Cryostat**	other objects not under the test are connected to the **Minus** terminal
B	**Bus-Bars**	**Yoke/ Cryostat**	other objects not under the test are connected to the **Minus** terminal
C	**Coil/Coils or Bus-Bars**	**Coil/Coils or Bus-Bars**	other objects not under the test are connected to the **Guard** terminal
D	**Temperature Sensors**	**Yoke/Cryostat +Coil/s+Bus-Bars**	all object which surrounds a temperature sensor shall be shorted together and connected to **Minus** terminal

4.11. The List of DC HV Tests of Nuclotorn Cable with Insulated Strands

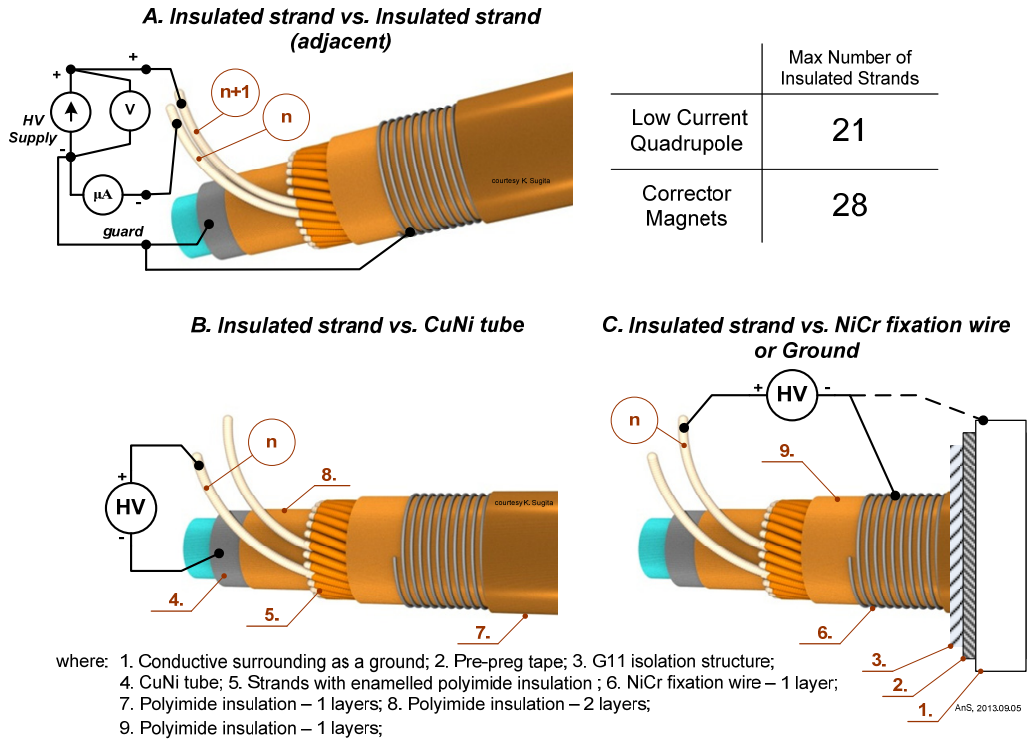
I. The Table 11 consists of DC High Voltage tests to be done on Nuclotorn Cable with Insulated Strands. Fig. 8 presents the cable and current test set up configurations.

Table 11. DC High Voltage Tests to be done on Nuclotron Cable with Insulated Strands.

	HV Tester terminals (positive polarity test)		**Remarks***
	Plus	**Minus**	
1	**Insulated strand (n)**	**Adjacent insulated strand (n+1)**	NiCr wire and CuNi tube are connected to the **Guard** terminal; NiCr wire** shall be connected from both sides of a cable other objects are not connected (floating)
2	**Insulated strand**	**CuNi Tube**	other objects are not connected (floating)*
3	**Insulated strand**	**NiCr fixation wire**	NiCr wire shall be connected from both sides of a cable, other objects are not connected (floating)*

* other set-up configuration shall be proved experimentally – if floating object shall be or shall not be connected to the minus or guard terminal of the HV Tester

**is recommended to prove if the NiCr wire has no break.



where: 1. Conductive surrounding as a ground; 2. Pre-preg tape; 3. G11 isolation structure;
4. CuNi tube; 5. Strands with enamelled polyimide insulation ; 6. NiCr fixation wire – 1 layer;
7. Polyimide insulation – 1 layers; 8. Polyimide insulation – 2 layers;
9. Polyimide insulation – 1 layers;

Fig. 8. View of SIS 100 correctors and SIS 100 Low Current Quadrupoles cable with configuration of testing set up for (positive polarity test): **A.** Insulated strand vs. Insulated strand (adjacent), **B.** Insulated strand vs. CuNi tube, **C.** Insulated strand vs. NiCr fixation wire or Ground.

5. Dedicated Tests

5.1. General requirements for Dedicated Tests

I. DC High Voltage tests have to be performed according to the agreement with the Customer. The Dedicated DC Test Program shall be discussed during a design reviews and it shall be accepted at latest before start of samples production. The Customer has right to participate and perform tests himself.

II. The test should be carried out at least in 3 steps – 3 different testing voltages (see section 4.3)

III. For the DC High Voltage Insulation test of Samples the test with positive and negative polarities are required for all testing voltages (V_{testA}, V_{testB}, V_{testC}).

IV. The ground for the End Coil Samples and Dummy/Test Coil testing has to be clearly defined; every sample shall be grounded in the same manner. A ground can be made using: wrapped foil, metallic plates, Baking Mold or immersion into conducting liquid. The Baking Mold is preferred solution. The method of grounding has to be accepted by the Customer.

V. All tests shall be performed at room temperature but above a dew point.

VI. The duration of the DC HV test of Dedicated Test is t_{test} =180s.

VII. The time of the object discharge after any test has to be at least 180s. In case of changing the voltage polarity 360s is required for the object discharge. Recording of the discharge current is recommended. The information on the discharge time has to be included in the test record.

VIII. The voltage and current recording during testing are mandatory.

IX. AC High Voltage tests (not part of this TG) have to be performed according to the agreement with the Customer. The Dedicated AC Test Program shall be discussed during a design reviews and it shall be accepted at latest 2 months before start of samples or Dummy/Test Coils production. The Customer has right to participate and perform tests himself.

5.2. Common Requirements for Samples

I. The End Coil and Coil Sample shall be made of the Dummy Cable or the SC Cable; the shape of samples should be similar to the most complicated part of the coil which is the coil end/head. The sample consists of several cables which are not electrically connected together and which are placed in the same manner (production technology and procedure) like the coil/winding cables. The example of End Coil Sample of the SIS100 Dipole during preparation is shown in Fig. 9.

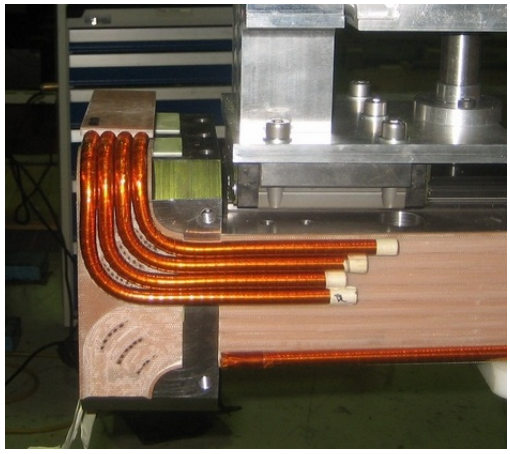


Fig. 9. Example of Nuclotron type End Coil Samples of SIS100 Dipole during preparation (courtesy BNG)

II. There are 2 types of samples:
- Sample before baking – to derive testing parameters and acceptance criteria for processes (technology) before baking.
- Sample after baking – to prove testing parameters and acceptance criteria after baking.

III. For testing of Sample before baking the testing voltage has to be increased slowly and the leakage current has to be monitored; the value of leakage current during test should not exceed 1μA.

IV. After finalising all the tests mentioned above, the DC break-down test of Samples before baking has to be performed:
   A. The diagram with the distribution of break-down voltages shall be prepared and delivered. The maximum, minimum, average and standard deviation values have to be calculated.
   B. Based on the break-down test the value of the test voltage before baking has to be derived and accepted by the Customer;
   currently, we state that the value of test voltage before baking $V_{test_before_baking}$ should be not higher than 60% of the maximum value of break-down voltage before baking; more adequate method (related to real tests distribution) for calculation of the $V_{test_before_baking}$ can be used after it is accepted by the Customer

C. After break-down tests these samples shall be baked and tested in the same manner as the Samples after baking.

V. The test of Samples before baking has to be done to derive the correct value of Vtest_before_baking for each type of magnet (for 'dry' and 'wet' coil technology) and minimum resistance acceptance criterion. The test procedure and Vtest_before_baking level have to be agreed by the Customer.

VI. After finalising all the tests, which were mentioned above, the DC break-down test of Samples after baking has to be performed:

A. The diagram with the break-down voltage distribution shall be prepared and delivered. The maximum, minimum, average and standard deviation values have to be calculated.

B. All break-down voltages have to be above $1.5*V_{test}$ (testing voltage required for a coil or bus-bar, see section 4.3) required for the related object under test.

VII. The independent cables on the Sample should be made in a way (distance between) which limits the possibility of the direct break-down between the ends of independent cables (cable vs. cable or strand vs. strand test) and between the cable and the ground during the break-down test.

VIII. Numbers of Nuclotron type End Coil Samples are presented in Table 12

Table 12 The number of Nuclotron type End Coil Samples

	SIS 100 Dipole	SIS 100 Quadrupole	SIS 100 Low Current Quadrupole	SIS 100 Correctors End Coil or Coil Sample***
Before Baking	1(2*)	1(2*)	1	1**
After Baking	1(2*)	1(2*)	1	1**
Total	2(4*)	2(4*)	2	2**

* in case of half End Coil Samples

** valid if all correctors are build by one Contractor, using the same components and technology

*** samples for SIS100 correctors can be build as an End Coil Sample or a Coil Sample (e.g. few turns coli with real dimension or as a solenoid)

5.3. Nuclotron type End Coil Samples and related HV Tests

I. The number of End Coil Samples of SIS100 Dipole and Quadrupole (one sample consists of several independent cables) should be sufficient to perform minimum 5 independent tests (see Table 12):

A. Cable vs. Ground (in this case the ground is the artificially made surrounding of the coil head),

B. Cable vs. Cable (two adjacent cables).

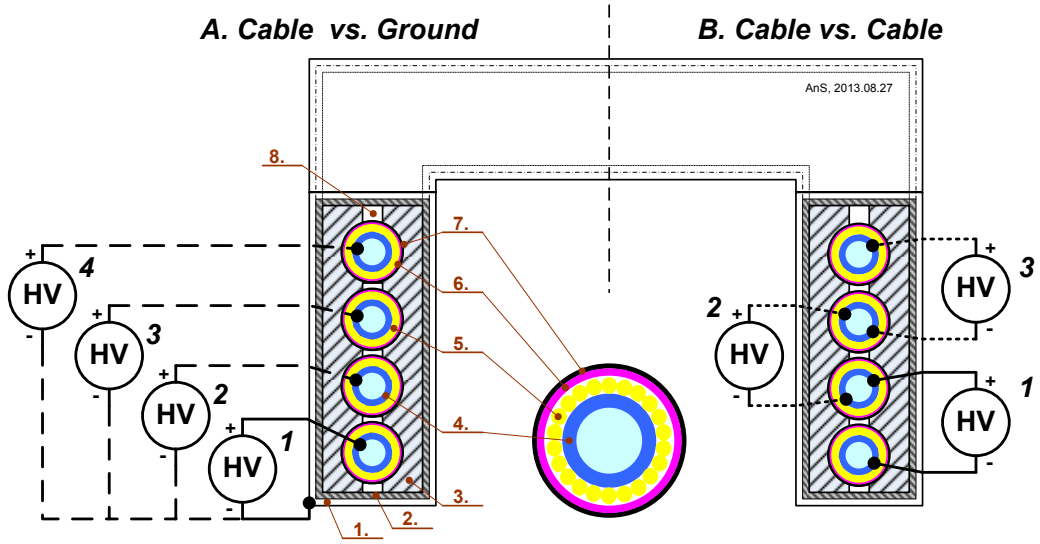


Fig. 10. The cross section of End Coil Sample (one pole = half of a coil) of SIS100 Dipole with configuration of testing set up for (positive polarity test):
A. Cable vs. Ground (4 tests)
B. Cable vs. Cable (3 tests)

where: 1. conductive surrounding as a ground; 2. pre-preg tape; 3. G11 isolation structure; 4. CuNi tube; 5. strands; 6. NiCr fixation wire – 1 layer; 7. polyimide insulation – 2 layers; 8. gaps between two G11 structures.

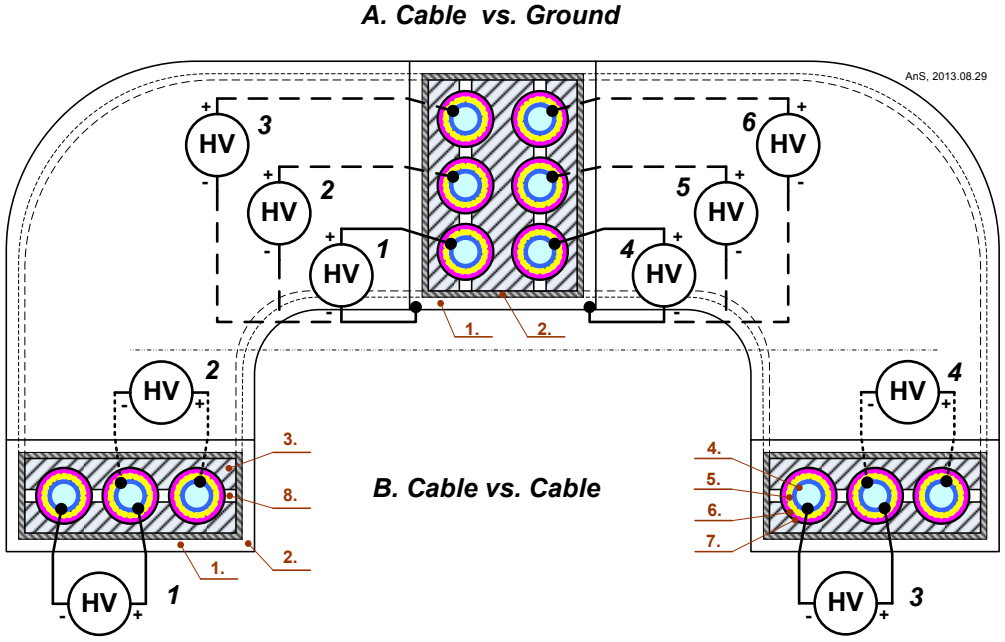


Fig. 11. The cross section of End Coil Sample (2 poles = half of a coil) of SIS100 Quadrupole with configuration of testing set up (positive polarity test):
A. Cable vs. Ground (6 tests)
B. Cable vs. Cable (4 tests)

II. The cross section of half (one pole) of End Coil Sample of SIS100 Dipole presents Fig. 10. The cross section of half (two poles) of End Coil Sample of SIS100 Quadrupole presents Fig. 11. Both figures present configurations of Cable vs. Ground and Cable vs. Cable tests. There is a requirement to prepare 2 half samples or one full sample of each to have more than 5 tests for each test configurations (see Table 12).

5.4. Nuclotron type End Coil Sample with Insulated Strands and related HV Tests

I. The End Coil Sample of Low Current Quadrupole has similar shape to presented in Fig. 11 and is made from Dummy Cable or SC Cable with insulated strands (see Fig. 8). The list of test are presented as follows:
   A. Each cable of the Sample shall be tested according to all tests presented in Table 11.
   B. Each insulated strand vs. Baking Mold
   C. All insulated strands vs. CuNi tube
   D. All Insulated strand vs. NiCr fixation
   E. All Insulated strand vs. Baking Mold,

The list of tests presented above will be verified after first sample testing.

5.5. Dummy Coil and/or Test Coil and related HV Tests

I. The Dummy/Test Coil shall be made of the Dummy Cable and it shall have similar electrical and geometrical features/properties like the FoS coil and the Series Coil. The construction of Dummy/Test Coil is modified in a way that artificial electrical insulation weakness and failures can be introduce purposefully for dedicated tests.

II. The Dummy/Test Coil has to fulfil all Acceptance Criteria (section 4.6) presented in this TG.

III. The Dummy/Test Coil is subjected for the Dedicated Test Program which shall be discussed during a design reviews and it shall be agreed at latest before the Dummy/Test Coil production.

IV. The construction of the Dummy/Test Coil has to be modified in a way that an electrical weakness (low or high resistance), short-circuit between turns and between coil and ground can be easily introduced.

V. The Dummy/Test Coil test presented in this TG shall be synchronised with the tests required for evaluation of a turn-to-turn insulation.

VI. The Dummy/Test Coil of SIS100 Dipole and Quadrupole shall be tested as follows:

   A. Coil vs. Ground (Baking Mold)
   B. Coil vs. Ground with low, medium, high leakage to the ground (not described in this TG).
   C. Turn-to-turn insulation (not described in this TG)
   D. Turn-to-turn with low, medium, high leakage between turns (not described in this TG)

   Dedicated Test program is presented in section 5.6.

VII. For testing of SIS100 Dipole and Quadrupole Dummy/Test Coils before baking the testing voltage has to be increase slowly and the leakage current has to be monitored; the value of leakage current during test should not exceed 10μA.

VIII. The tests of Dummy/Test Coil of SIS100 Correctors and SIS100 Low Current Quadrupole **before** joints soldering shall be done as follows:

   A. The cable of the Dummy/Test Coil shall be tested according to all tests presented in Table 11.
   B. Each insulated strand vs. Baking Mold
   C. All insulated strands vs. CuNi tube
   D. NiCr fixation wire continuity, if possible
   E. All Insulated strand vs. NiCr fixation wire
   F. NiCr fixation wire vs. Baking Mold
   G. All Insulated strand vs. Baking Mold

   Dedicated Test program is presented in section 5.6.

IX. The tests of Dummy/Test Coil of SIS100 Correctors and SIS100 Low Currnt Quadrupole **after** joints soldering shall be done as follows:
   A. Coil vs. Ground (ground: CuNi tube, NiCr fixation wire, Baking Mold, yoke, another external ground)
   B. Coil vs. Ground with low, medium, high leakage to the ground.
   C. MID wire (dedicated wire for Mutual Inductance Detector) vs. all other elements of a cable
   D. Turn-to-turn insulation (not described in this TG)
   E. Turn-to-turn with low, medium, high leakage between turns (not described in this TG)

X. For testing of Dummy/Test Coil of SIS100 Correctors and Low Current Quadrupole before baking the testing voltage has to be increase slowly and the leakage current has to be monitored; the value of leakage current during test should not exceed 1μA for single strand and 10μA when all strands are tested together.

5.6. Dedicated Dummy/Test Coil Test Program

I. Dedicated Test Program of the Dummy/Test Coil during production is presented in Table 13. The content of the table is based on the production plan of SIS100 FoS Dipole. Therefore presented program is directly applied for SIS100 Dipole and Quadrupole.
II. The characteristic of leakage current during cool-down shall be measure for temperature below 40^{o}C up to room temperature.
III. The cable of SIS100 Correctors and Low Current Quadrupoles consists of insulated strands (Fig. 8). Therefore for them more tests (see sections 4.11, 5.5.VIII and 5.5.IX) are required for each step presented in Table 13.
IV. The pressure applied on a Baking Mold shall guarantee very good connection between the coil surface and the Baking Mold plates.

Table 13 Dedicated Dummy/Test Coil Test Program during production at room temperature.

Nr	Production Steps Description	Object	HV Tester terminals (positive polarity test)	
			Plus	Minus
01	Reception Tests	Materials for coil production according to the specification		
02	During or after coil winding	Coil on Winding Machine	Coil	Winding Machine
03	After installation of 'wires' for hardware simulation of electrical failures	Coil stand alone or on winding machine	to be decided	
04	After coil winding	Coil stand alone	to be decided	
	After coil installation into a Baking Mold, 1st baking process			
05	No forces/ pressure is applied on the Baking Mold	Coil in Baking Mold	not yet foreseen	
06	A force/pressure is applied on Baking Mold; sufficient to guarantee good connection between coil surfaces and Baking Mold	Coil in Baking Mold	Coil	Baking Mold
07	After a force/pressure is released	Coil in Baking Mold	to be decided	
08	Final force/pressure is applied on the Baking Mold (if applicable)	Coil in Baking Mold	Coil	Baking Mold
09	During 1st Baking	Coil in Baking Mold	**no HV tests**	
10	After 1st Baking during Cool-Down	Coil in Baking Mold	to be decided	
11	After 1st Baking at room temperature; a force/pressure is applied on the Baking Mold; sufficient to guarantee good connection between coil surfaces and Baking Mold	Coil in Baking Mold	Coil	Baking Mold
12	After removing the coil from a Baking Mold	Coil stand alone	to be decided	
13	After Pre-preg wrapping	Coil stand alone	to be decided	
	After coil installation into a Baking Mold, 2nd baking process			
14	No forces/ pressure is applied on the Baking Mold	Coil in Baking Mold	not yet foreseen	
15	A force/pressure is applied on Baking Mold; sufficient to guarantee good connection between coil surfaces and Baking Mold	Coil in Baking Mold	Coil	Baking Mold
16	After a force/pressure is released	Coil in Baking Mold	to be decided	
17	Final force/pressure is applied on the Baking Mold (if applicable)	Coil in Baking Mold	Coil	Baking Mold
18	During 2nd Baking	Coil in Baking Mold	**no HV tests**	
19	After 2nd Baking during Cool-Down	Coil in Baking Mold	Coil	Baking Mold
20	After 2nd Baking at room temperature; a force/pressure is applied on the Baking Mold; sufficient to guarantee good connection between coil surfaces and Baking Mold	Coil in Baking Mold	Coil	Baking Mold
21	After removing the coil from a Baking Mold	Coil stand alone	to be decided	
22	After insertion of the coil into related yoke	Coil in yoke	Coil	Yoke

6. Extended Test Programs

I. The First of Series (FoS) components (coil, bus-bar, magnet, unit, module) are the subject for the Extended Test Program. The frame for the Extended Test Program shall be discussed during a reviews, and after Dummy/Test Coil test is completed and before FoS coil production starts shall be agreed at latest.

II. The First of Series (FoS) components (coil, bus-bar, magnet, unit, module) have to fulfil Acceptance Criteria presented in this TG and all additional requirements derived after the tests of the Samples and Dummy/Test Coils are completed.

III. Both polarities test is applicable for all DC High Voltage tests of FoS components (like coil, bus-bar, magnet, unit, module) .

6.1. First of Series SC Coil Production

I. The basis for the Extended Test Program of the FoS Coil is the Dedicated Test Program of the Dummy/Test Coil (section 5.6).

II. The final version of the Extended Test Program shall be derived after the Dummy/Test Coil tests is completed and analysed.

III. The cable of SIS100 Correctors and Low Current Quadrupoles consists of insulated strands (Fig. 8). Therefore for them more tests (see sections 4.11, 5.5.VIII and 5.5.IX) are required for each step presented in Table 13.

6.2. First of Series SC Unit/SC Module Production

I. The Extended Test Program for the First of Series of SC Unit/SC Module Production is similar to the Standard Test Program described in section 7.2. The difference is the extended number of tests and using the positive and negative polarities tests. Other testing methods can be applied; therefore additional time for tests performance shall be counted.

6.3. First of Series SC Unit/SC Module Testing at Cold/Cryogenic Condition

I. The Extended Test Program for testing at cold/cryogenic condition of the First of Series of SC Unit and SC Module is presented in Table 14.

Table 14. Extended Test Program of the First of Series at Cold/Cryogenic Condition

Nr	**Steps Description**	**Tests to be done/ Remarks**
1	Reception Test	according to the specification recommended: DC HV tests: A, B , C , D according to Table 10
2	After preparation on a preparation bench (if electrical integrity is affected)	DC HV tests: A, B, C, D according to Table 10
3	After placing on a test bench before connection to the testing infrastructure	
4	After connection to the testing infrastructure	
5	After closing a magnet cryostat before pumping	
6	After pumping (vacuum)	
7	During cool-down	
8	After cool-down before first powering (1st cool-down)	
9	After first powering	
10	After last powering	
11	After warm-up and pumping (vacuum) before cool-down	
12	After cool-down before powering (2nd cool-down)	
13	After powering	
14	After warm-up and pumping (vacuum) before cool-down	
15	After cool-down before powering (3rd cool-down)	
16	After powering	
17	After warm-up before disconnection	
18	After disconnection from Test Bench	
19	Preparation for: • outside transportation, • storage, • tunnel installation.	according to the specification recommended: DC HV tests: A, B , C , D according to Table 10

6.4. The beginning of the Series Production

I. The beginning of the series production shall be subjected for the Extended Test Program.

II. The current version of TG suggests the first 2 magnets of each type of magnet of series production shall be subjected for the Extended Testing Program. The decision about the fraction of the production to be subjected to the Extended Test Program shall be made during the Final Design Review and verified after Dummy and FoS Coils tests.

III. The final test program for the beginning of series production shall be specified and verified after the Dummy/Test Coil and the FoS Coil tests were performed and analysed.

IV. After reaching stable production quality the testing program will be reduced to the Standard Test Program which is presented in this TG in chapter 7.

7. Standard Test Programs for Series Production

I. The beginning of the series production shall be subject for the Extended Test Program (see section 6.4). After achieving stable production quality the testing program will be reduced to Standard Test Programs which are presented in this chapter.

II. The positive polarity and 3-step voltages procedure (section 4.5) are default for the Standard Test Program. In case the conclusion of the Dummy/Test Coil or/and FoS coil testing is that both polarities test is recommended, the positive and negative polarity tests become mandatory.

III. All DC HV tests shall be performed on room temperature but above due point.

IV. The coils, bus-bars and temperature sensors are the independent circuits to be tested.

V. More detailed information about the test performance and the evaluation criteria are provided in chapter 4.

VI. A temperature sensor shall not be placed on a non-insulated superconducting coil, bus bar, cable or conductor which is a part of live electrical circuit. In case that temperature sensor is directly connected to the live circuit the required DC high voltage test shall be done before temperature sensor installation (see section 4.3 and 4.9).

VII. The Contractor is encouraged to adjust the proposed Standard Test Program to his own production process, following the requirements given in chapter 4 and chapter 7.

7.1. DC HV Insulation Test of the SIS100 SC Coil and Bus-Bars Production

I. DC High Voltage Insulation Test shall be performed between a coil / bus-bar and the ground after a coil/bus-bar winding, before and after a coil/bus-bar baking. There are several possibilities to perform high voltage tests on a coil:

   a. a coil shall be wrapped around by the conduction foil which constitutes the ground,
   b. a coil shall be inserted into the Baking Mold which constitutes the ground,
   c. a coil is immersed in conducting liquid which constitutes the ground.

   A Baking Mold is recommended ground.

II. The Standard Test Program for the electrical insulation tests of a coil/ bus-bar production is described in Table 15.

Table 15. The Standard Test Program of the DC High Voltage Insulation Test of a SC Coil and Bus-bars during production at room temperature.

Nr*	Production Steps Description	Object	HV Tester terminals (positive polarity test)	
			Plus	Minus
01	Reception Tests	Materials for coil production according to the specification		
02	During or after coil winding	Coil on Winding Machine	Coil	Winding Machine
03-04	not applied			
	After coil installation into a Baking Mold, 1st baking process			
05	not applied			
06	A force/pressure is applied on Baking Mold; sufficient to guarantee good connection between coil surfaces and Baking Mold	Coil in Baking Mold	Coil	Baking Mold
07-10	not applied			
11	After 1st Baking at room temperature; a force/pressure is applied on the Baking Mold; sufficient to guarantee good connection between coil surfaces and Baking Mold	Coil in Baking Mold	Coil	Baking Mold
12	After removing the coil from a Baking Mold	Coil stand alone	to be decided	
13	not applied			
	After coil installation into a Baking Mold, 2nd baking process			
14	not applied			
15	A force/pressure is applied on Baking Mold; sufficient to guarantee good connection between coil surfaces and Baking Mold	Coil in Baking Mold	Coil	Baking Mold
16-19	not applied			
20	After 2nd Baking at room temperature; a force/pressure is applied on the Baking Mold; sufficient to guarantee good connection between coil surfaces and Baking Mold	Coil in Baking Mold	Coil	Baking Mold
21	After removing the coil from a Baking Mold	Coil stand alone	to be decided	
22	After insertion of the coil into related yoke	Coil in yoke	Coil	Yoke

* Numbers refer to positions in Table 13
** Optional tests
*** The testing voltages shall be carefully considered (see section 5.5)

7.2. DC HV Insulation Test of the SIS100 SC Magnet Production

I. The Standard Test Program for the DC High Voltage Insulation tests of the SC Magnet, is presented in Table 16.

Table 16. The Standard Test Program of the DC High Voltage Insulation Test of the SIS100 SC Magnets, during production at room temperature

	SIS100 SC Magnets Production Steps Description	**Tests to be done/Remarks**
1	Reception Tests	SC coil/ bus-bar and other components according to the specification recommended: DC HV tests: A, B according to Table 10**
2	**After** a coil insertion into a yoke, **after** soldering all voltage-taps to a coil, **after** soldering all voltage-taps to bus-bars and **after** bus-bars installation on a yoke	DC HV tests: A, B, C according to Table 10** free ends of all voltage taps shall be insulated
3	After temperature sensors installation	DC HV tests: D according to Table 10**
4	After completion of SC Magnet assembly	DC HV tests: A, B, C, D according to Table 10** free ends of all voltage taps shall be insulated

*A temperature sensor shall not be placed on a non-insulated superconducting coil, bus bar, cable or conductor which is a part of live electrical circuit. In case that temperature sensor is directly connected to the live circuit the required DC high voltage test shall be done before temperature sensor installation (see section 4.3 and 4.9).
** For the SC magnets with insulated strands the additional tests according to the Table 11 shall be performed.

II. The Standard Test Program for the DC High Voltage Insulation tests of the SC Magnet with insulated strands shall be prepared based on Table 16 , Table 11 and description in section 5.5 points VIII and IX.

7.3. DC HV Insulation Test of the SIS100 SC Dipole Module Production

I. The Standard Test Program for the DC High Voltage Insulation tests of the SC Dipole Module during production at room temperature is presented in Table 17.

Table 17. The Standard Test Program of the DC High Voltage Insulation Test of the SIS100 Dipole Module during production at room temperature

	SIS100 SC Dipole Module Production Steps Description	**Tests to be done/Remarks**
1	Reception Test	SC Magnet and other components according to the specification recommended: DC HV tests: A, B, C, D according to Table 10
2	**After** insertion of the dipole magnet into a cryostat **before** soldering all voltage-taps and sensors wires into the related sockets	DC HV tests: A, B, C, D according to Table 10 free ends of all voltage taps shall be insulated
3	**After** insertion of the dipole magnet into a cryostat **after** soldering all voltage-taps and sensors wires into the related sockets	DC HV tests: A, B, C, D according to Table 10
4	**Before** shipping to the Customer for testing at cold/cryogenic condition	

7.4. DC HV Insulation Test of the SIS100 SC Quarupole Unit and Doublet Module Production

I. The Standard Test Program for the DC High Voltage Insulation tests of the SC Quarupole Unit and Doublet Module Production at room temperature is presented in Table 18

Table 18. The Standard Test Program of the DC High Voltage Insulation Test of the SIS100 Quadrupole Unit and Doublet production at room temperature

	SIS100 SC Quadrupole Module Production Steps Description	**Object**
1	Reception Test	SC Magnet and other components according to the specification recommended: DC HV tests: A, B, C, D according to Table 10
2	**Quadrupole Unit* Assembly**	
2.1	**After** all components (magnet, correctors, bus-bars, sensors, other components,) are installed on the common structure (connected to a quadrupole magnet)	optional
2.2	**After** insertion of Unit into cryostat **before** soldering all voltage-taps and sensors wires into related sockets.	DC HV tests: A, B, C, D according to Table 10
2.3	**After** insertion of Unit into cryostat **after** soldering all voltage-taps and sensors wires into related sockets.	
2.4	**Before** sending a Unit for tests at cold/cryogenic condition	
3	**Tests at cold/cryogenic condition**	see section 7.5
4	**Before shipping to a Contractor for Quadrupole Doublet* Assembly**	DC HV tests: A, B, C, D according to Table 10
5	**Quadrupole Doublet* assembly**	
5.1	**After** all components (magnets, bus-bars, other components, sensors) are installed on the common girder structure.	DC HV tests: A, B, C, D according to Table 10
5.2	**After** insertion of Doublet into cryostat **before** soldering all voltage-taps and sensors wires into the related sockets.	
5.3	**After** insertion of Doublet into cryostat **after** soldering all voltage-taps and sensors wires into the related sockets.	
5.4	**Before shipping to the Customer**	

7.5. The Test Program for Cold Testing (Nominal Condition) of Series Production

I. The Standard Test Program for the electrical insulation test of a SC unit / SC Module at nominal condition (cold tests) is described in Table 19.

Table 19. The Standard Test Program of DC High Voltage Insulation Test of a SC Magnet and SC Unit at nominal condition (cold test).

Nr*	**Steps Description**	**Tests to be done/Remarks**
1	Reception Test	according to the specification recommended: DC HV tests: A, B, C, D according to Table 10
2	After preparation on a preparation bench (if electrical integrity is affected)	optional
3	After placing on a test bench before connection to the testing infrastructure	recommended
4	After connection to the testing infrastructure	DC HV tests: A, B , C , D according to Table 10
5	After closing a magnet cryostat before pumping	optional
6	After pumping (vacuum)	optional
7	During cool-down	recommended
8	After cool-down before first powering (1st cool-down)	DC HV tests: A, B , C , D according to Table 10
9	After first powering	optional
10	After last powering	DC HV tests: A, B , C according to Table 10
11	After warm-up and pumping (vacuum) before cool-down	DC HV tests: A, B , C according to Table 10 required if the SC magnet is subjected for next cool-down: - fraction of the series production - due to weak quench performance
12	After cool-down before powering (2nd cool-down)	
13	After powering	
14	After warm-up and pumping (vacuum) before cool-down	
15	After cool-down before powering (3rd cool-down)***	
16	After powering***	
17	After warm-up before disconnection (no vacuum)	DC HV tests: A, B , C according to Table 10
18	After disconnection from Test Bench	DC HV tests: A, B , C , D according to Table 10
19	Preparation for: • outside transportation, • storage, • tunnel installation.	according to the specification recommended: DC HV tests: A, B, C, D according to Table 10

* Numbers refer to positions in Table 14
** Powering means to power a coil with nominal current – e.g. magnetic measurements, quench training, magnet pulsing.
*** The third run is not foreseen for series SC magnets only for fraction of the series production.

II. The Contractor is encouraged to adjust the proposed test program to his own testing program, following the requirements given in chapter 4, Table 10 and Table 19.

III. In Table 19 several positions have the status optional. These positions are not foreseen for the standard test. Nevertheless the Contractor has to take into account a time slot for performing optional tests. They can be request by Customer for certain fraction of the production or in case of unexpected behaviour during standard test.

8. Test Record

I. All tests, described in this TG shall be performed and documented in the record in written/printed and electronic forms. The minimum content of the record are presented in following sections.

8.1. Standard Informational Contents of the Test Record

I. Minimum requirements for the information content of the record (written/printed and electronic forms):
   A. Test identification
   B. Address of the Company or Institute and Department Identification, where applicable.
   C. Place where the test was performed.
   D. Date when the test was performed (date, time and duration).
   E. Names of the testing personnel (who performed the test).
   F. Name of the test leader or the quality engineer, if applicable.
   G. Identifier and the serial number of the object under test.

II. Minimum requirements for measurement equipment documentation are:
   A. Device identification (name, serial number, inventory number).
   B. Date of last calibration (the calibration certificate should be attached to the documentation) and date of next calibration
   C. Date of last checking/proof test and date of next checking/proof test, if the calibration certificate is not available (for self made testing equipment).

8.2. Measurement Conditions Documented in the Test Record

I. Minimum requirements for the measurement conditions documentation:
   A. The ambient/room temperature, humidity and pressure in the testing area (place where the test was performed),
   B. The temperature of the object under test, it is recommended that the object temperature is equal to the ambient temperature. It has to be clearly stated if the temperature of the object was different then ambient temperature (e.g. during the cold test or after transportation between areas of different temperature).
   C. For test after connection to testing infrastructure additionally isolation vacuum pressure.

II. Operator must ensure that the object is clean and no moisture exists in areas of electrical connectors and insulation surface of current leads (after connection to testing infrastructure) – this information should be stated in test record.

8.3. DC High Voltage Insulation Test Record Requirements

I. Brief description of the testing process,
II. Test scheme, if applicable.
III. Relevant instruments settings (e.g. applied measuring ranges or corresponding settings).
IV. All required measurement results. Ion case of 3 voltage step tests (see section 4.3) all 3 test shall be included in to one record.
V. All specific measurement conditions and results, not included in section 8.2.
VI. In case the test/measurements was repeated, all results have to be collected.

8.4. Test Results Evaluation

I. Test results evaluation shall be done according to Acceptance Criteria listed in section 4.6 :
    A. Minimum Resistance Acceptance Criteria (section 4.7)
II. Additional test results processing shall be done according to description in section 0:
    A. Processing of Step Voltage Tests
    B. Analysis of Leakage Current Decay
    C. Comparative Analysis of the Test Results for Similar Objects at Similar Testing Conditions
    D. Comparative Analysis of the Test Results for the One Object at Similar Testing Condition
III. The documentation of all defined tests and procedures shall be signed by the executing personnel. The test record has to be signed by the person who performed the test. In case that evaluation/acceptation was done by other person the name and signature of this person has to be included in the test record.
IV. On the conclusion page it has to be indicated that all required tests have been performed and the Acceptance Criteria were fulfilled.
V. In case a test does not comply with Acceptance Criteria the Non-Conformity has to be created and object under test is rejected; a short description has to be provided in the record.
VI. The test record shall be crosschecked and signed by the person responsible for the product quality.

9. Data Management

I. The original test records must be handed out to the Customer as a part of the Travel Book.
II. An electronic version of the test record shall be stored in a file format agreed by the Customer (in case of EDMS data base, relevant guidelines for EDMS access and usage have to be applied).
III. Registration of all Non-Conformities.
IV. A file with raw test data has to be delivered in the ASCII format or in other format agreed on by the Customer. All important information related to test identification, shall be included in the header (first part) of the file.

10. References

[1] Recommended Practice for Insulation Testing of AC Electric Machinery (2300V and Above) with High Direct Voltage, IEEE Std 95-2002 (R2007)

[2] Recommended Practice for Testing Insulation Resistance of Rotating Machinery, IEEE Std 43-2000 (R2006)

[3] “A Stitch In Time” The Complete Guide to Electrical Insulation Testing –Megger 2006