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SPECIFICATION OF A COAXIAL HIGH VOLTAGE (300 KV DC) CABLE FOR THE CERN PS ELECTROSTATIC SEPTA

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Specification of a coaxial High Voltage (300 kV DC) cable for the CERN PS electrostatic septa

1. Compatibility with existing material

In the CERN PS accelerator two electrostatic septa are installed. They are used for extraction of the accelerated particles towards the SPS accelerator and the East Area experimental hall. These septa are supplied with high voltage (HV) from generators placed in the centre of the accelerator. The generators are connected to the septa by means of approximately 160 m long HV cables. This specification describes this cable, which is to be compatible with the existing cable and infrastructure (connectors, bending radius and electrical performance).

2. Required electrical performance:

The maximum operating voltage will be 300 kV. The central conductor will be charged to a negative voltage, and the metallic screen will be on ground potential.

The maximum operating current will be 200 μA at 300 kV.

The high voltage will be applied continuously with only occasional interruptions. Charging and discharging is done with a resistor of 300 MΩ in series. However, in case of failure in a resistor, a connector or the septum, a rapid discharge can occur, including polarity reversal by reflection of the discharge wave at one end of the cable. The cables must withstand these transients without damage. The total length for which this failure can occur is about 160 meters.

The total leakage current for a 200 m long cable charged to 300 kV must be less than 1μA. This means the leakage resistance should be higher than 3.10^{11} Ω.

The minimum bending radius of the installed cable shall be less than 0.5 m. The manufacturer must specify the bending radius allowed during the installation of the cable. This value should be smaller than 0.7 m.

3. Cable construction

3.1 Cable compatible with existing connectors

This paragraph refers to a 100 % compatible cable with the existing infrastructure, i.e. identical electrical cable performance and with the same dimensions.

For safety reasons the cable shall be absolutely halogen and sulphur free. It shall consist of the following layers (where applicable the construction of the existing cable is mentioned):

- Central conductor (existing cable: 16mm^2, ∅ 4.9 mm)
- Inner semi conducting layer
- Insulation; the outer diameter of the insulation should not exceed 25.4 mm (existing cable: 9.9 mm for the oiled paper insulation and 25.2 mm for polyethylene)
- Outer semi-conducting layer
- Metallic screen (on existing cable this is a copper braid, external diameter 27.5 mm)
- Insulating outer sheath; the outer diameter is expected to be around 31 mm (existing cable 31.1 mm)

Central conductor

The central conductor may be of twisted, plain or metal coated annealed copper, or of twisted, plain or metal coated aluminium alloy. Other variants can also be considered. The existing cable consists of 7 twisted annealed copper conductors (total cross section 16mm^2), with an outer diameter of 4.9 mm.

Conductor screening

The central conductor screening must consist of a semiconductor compound.

Insulation

The insulation can be an extruded single layer solid dielectric of one of the following insulating compounds:

- low density thermoplastic polyethylene (PE)
- high density thermoplastic polyethylene (HDPE)
- cross-linked polyethylene (XLPE)
- Ethylene propylene rubber (EPR).

In the existing cable close to the central conductor an oil / paper insulation is used. Other dielectrics, in particular PVC, are excluded.

Insulation screening

The insulation screening must consist of an outer non-metallic semi-conducting layer in combination with a metallic screen.

The non-metallic layer must be applied directly upon the insulation and shall consist of either semi-conducting tape or of extruded semi-conducting compound, preferably extruded during the same operation as the dielectric. CERN has a strong preference for an extruded and easily strippable semi-conducting layer.

The metallic screen must consist of one or more tapes, or braid or a concentric layer of wires or a combination of tapes and wires, applied without discontinuity per manufactured length.

Insulating outer sheath

An outer non-metallic protective sheath must surround the cable. Because of the fire safety requirements halogen free material must be used (for example PVC is excluded).
The protective sheath must assure that the cable is fully watertight and provide an appropriate insulation for a DC voltage of 6 kV applied between the metallic screen and the metallic clamps fixing the cable on a tray.
Furthermore, the mechanical strength of this insulating outer sheath must be sufficiently high to protect the cable against mechanical damage, especially during its installation.

Dimensional tolerances

After installation the cables will be fitted with connectors and therefore the following dimensional tolerances must be observed:

Maximum variation of insulation thickness ±0.2 mm, maximum outer diameter $25.4\ ^{+0.0}_{-0.5}$mm

Maximum deviation of the outer contour of the insulation from the nominal cylinder concentric with the central conductor 0.5 mm.

3.2 Cable compatible with alternative type (160 kV) connectors

If a cable with the required dimensions as described in §3.1 proves to be unattractive to manufacture, a second type of connector may be adapted to our systems. An offer for cable compatible with these connectors may be considered. These connectors accept a cable with an insulation diameter of 31.0 mm, and a total outer diameter of 41.5 mm. Except the modified dimensions, all requirements mentioned in this specification must be respected, however, paper oil insulation will be excluded. The central conductor diameter may be reduced if required, but should remain big enough to allow a plug to be fitted. Before the cable design can be accepted, the compatibility with the alternative connector will have to be verified.

4. Particular requirements

For use of these HV cables in the CERN accelerator tunnels the cable must comply with the following particular CERN requirements.

4.1 Fire safety

In table 1 the required properties for electric cables with respect to fire safety are shown, according the CERN safety instructions IS 23.

Table 1: required properties with respect to fire safety and radiation resistance

PROPERTY	STANDARD	REQUIREMENTS	REMARKS
Flame and fire propagation	IEC 332-3	Pass	Category CF
Smoke density	IEC 1034--1 and 2	Pass	
Toxicity of fire gases	ATS 1000.001	HF <100 HCL<150 HCN<150 SO2 + H2S < 100 CO < 3500 NO+NO2 < 100	Mean value in ppm of at least 3 samples obtained within 4 minutes under flaming and non flaming conditions
Corrosivity of the fire gases	IEC 754-2	PH>4 and conductivity < 100 µS/cm	The cable shall be halogen and sulphur free (less than 0.1 % by weight)
UV resistance	IEC 68-2-5	No discoloration No stickiness	Procedure C, 10 days 40°C
Radiation resistance	IEC 544-2 and 4	Radiation index > 5.7	Elongation at break (ISO37) 50% of initial value at absorbed dose of 5.10^5 Gy. Test at high dose rate (>1 Gy/s)
Temperature index of sheath	BS 2782, Part 1	Pass	FT > 260°C Length burnt < 50 mm

4.2 Radiation resistance (IEC 544)

The cable will be in service for at least 10 years. During this period the cable can be exposed to an integrated dose of 10^6 Gy, and must fully retain its functional capabilities.

4.3 Compatibility with insulating liquids

All materials of the cable shall be fully compatible with the following insulating liquids used at CERN

Fluoroinert FC 77 (3M)
Diala B mineral oil (SHELL)
In the past also Silicon oil (electrical quality) compatibility was required, but can be omitted if necessary

5 Tests procedures

For the construction and testing of HV DC cables no appropriate IEC standards or other recommendations exist. For compatible AC power cables publication IEC 60840 Ed 2.0 is available with the title "Power cables with extruded insulation and their accessories for rated voltages above 30 kV (Um = 36 kV) up to 150 kV (Um = 170 kV) - Test methods and requirements". In absence of another publication most of the type and routine tests shall be carried out according this IEC publication and meet the requirements defined here. The references in brackets in this chapter refer to the paragraphs of this publication.

For the purpose of the AC tests of the cable the equivalence between the maximum operating DC voltage U_{DC} = 300 kV and the value of U_0 on which the test voltages are based shall be as follows (inverse application of §13.1.2):

$$U_0 = \frac{1}{3}U_{DC} = 100kV$$

The rated AC voltage of the cable is defined as (§8.4):

$$U = \sqrt{3}.U_0 \approx 170kV$$

The following tests (if applicable) will be required. CERN may, at its own discretion, accept an incomplete set of tests. The details of the tests to be performed shall be settled in an agreement between CERN and the manufacturer before signature of the contract.

5.1 Routine tests

These tests should be performed in the following order.

- Dimensional check, and aspect
- Resistance measurement of the inner conductor
- Resistance measurement of the outer conductor
- HV DC test 300 kV, 30 minutes
- Leakage current test
- Power frequency test $2U_0$ = 200 kV for 2 hours (or §9.3)
- Discharge test at U_{DC} on 500 m cable: with 100 discharges to earth through low inductance spark gap
- 6 kV DC between metallic screen (outer conductor) and ground potential to test outer sheath. Duration 1 minute (or according to §9.4).
- Partial discharge test at 50 Hz. In the past the cable was powered up to 61 kV and measurement took place at 52.5 kV, max. 5 pC. However the values of §9.2 are higher, and before signing the contract, CERN and the supplier will have to agree on the values that will be respected.

5.2 Sample tests

- Sample tests (§10.4, §10.6, §10.8, §10.9, §10.10, §10.11)
- Sample tests on approximately 20 m cable with negative DC voltage:
    - 350 kV 15 minutes (guaranteed value)
    - 400 kV 15 minutes (for indication only)

5.3 Type tests

In accordance with the afore mentioned IEC publication, the type tests will not be required if they have already been satisfactorily performed by the manufacturer on cables of a similar type, and a similar overall construction.

- Type tests (§11.3.4, §11.3.5, §11.3.8, §11.3.9, §11.4)
- Impulse voltage test at 750 kV for 10 pulses
- Power frequency test at 2.5 U_0 = 250 kV for 15 min.

5.4 Type tests to CERN particular requirements

Radiation damage test according to IEC 544
Fire test according to IEC 332-3

6 Conditioning

The minimum length manufactured without discontinuity shall not be shorter than 500 m. The total order will not be less than 1000 m.

The cables shall be delivered on drums covered with boards, PVC foil or similar. The drum shall be covered with wooden planking. At least four meters of both ends of the cable on each drum shall be accessible to allow electrical tests. Each drum must bear the following indications:

- number of contract
- type of cable
- unit length per cable
- number of unit lengths
- identification of the cable in CERN nomenclature
- net and gross weight
- drum number
- unrolling direction
- specific electrical capacitance.

The type and manufacturer should be marked on the cable.

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