Cryogenic High Voltage Insulation Breaks for ITER

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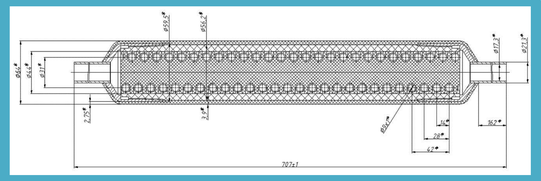
Abstract: High voltage insulation breaks are used in cryogenic lines with gas or liquid (helium, hydrogen, nitrogen, etc.) at a temperature range of 4.2-300 K and pressure up to 30 MPa to isolate the parts of an electrophysical facility with different electrical potentials. In 2013 NIIEFA delivered 95 high voltage insulation breaks to the IO ITER, i.e. 65 breaks with spiral channels and 30 breaks with uniflow channels. These high voltage insulation breaks were designed, manufactured and tested in accordance with the ITER Technical Specifications: «Axial Insulating Breaks for the Qualification Phase of ITER Coils and Feeders». The high voltage insulation breaks consist of the glass-reinforced plastic cylinder equipped with channels for cryoagent and stainless steel end fittings. The operating voltage is 30 kV for the breaks with spiral channels (30 kV HV IBs) and 4 kV for the breaks with uniflow channels (4 kV HV IBs). The main design feature of the 30 kV HV IBs is the spiral channels instead of a linear one. This approach has enabled us to increase the breakdown voltage and decrease the overall dimensions of the high voltage insulation breaks. In 2013 the manufacturing technique was developed to produce the high voltage insulation breaks with the spiral and uniflow channels that made it possible to proceed to serial production. To provide the acceptance tests of the breaks the special test facility was prepared. The helium tightness test at 10^{-11} m^3•Pa/s under the pressure up to 10 MPa, the high voltage test up to 135 kV and different types of mechanical tests were carried out at the room and liquid nitrogen temperatures.

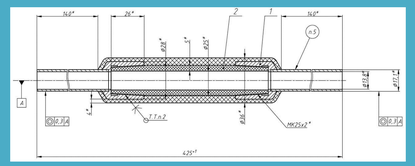
30kV HIGH VOLTAGE INSULATION BREAKS

4kV HIGH VOLTAGE INSULATION BREAKS

DESIGN INSULATION BREAKS



30kV HIGH VOLTAGE INSULATION BREAK



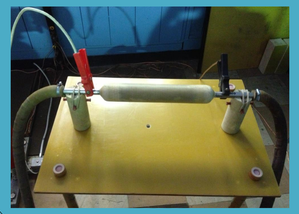
4kV HIGH VOLTAGE INSULATION BREAK

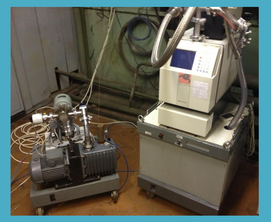
SET-UP FOR TESTS

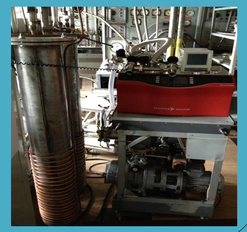
HV DC test
Power supply:
AC/DC, 120kV, 10 Ma
Criterion of current
DC: 6/15 mkA
AC: 10/100 mkA

Leak tightness test
Range of helium leak detector from10^0 Pa·m^3/c to 10^{-12} Pa·m^3/c
Criterion of leak tightness – $1\cdot10^{-9}$ Pa·m^3/c

Thermal cycles test
Range of helium leak detector from10^0 Pa·m^3/c to 10^{-12} Pa·m^3/c
Criterion of leak tightness - $1\cdot10^{-9}$ Pa·m^3/c
Thermal cycles:5,Cycle time: 60 min







ACCEPTANCE TESTS

The following tests were carried out for each 30kV and 4kV HV IB according to the Test Program and ITER Technical Specifications:
30kV HV IB:
- Input test: visual inspection, flow test, leak tightness.
- Leak test under pressure of 3.9MPa.
- High-voltage test No. 1: 35kV – DC, 25kV – AC (1.2-1.3 bar, helium).
- Five thermal cycles in the temperature range of 300-77K.
- Five pressure/leak test cycles: 3.9MPa at 77K and at the room temperature.
- High-voltage test No. 2: 35kV – DC, 25kV – AC, partial discharge (1.2-1.3 bar, helium).

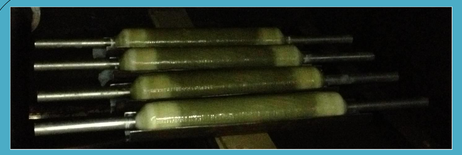
4kV HV IB:
- Input test: visual inspection, leak tightness.
-- Leak test under pressure of 1.95MPa.
- High-voltage test No. 1: 5kV – DC, 3.5kV – AC (1.2-1.3 bar, helium).
- Five thermal cycles in the temperature range of 300-77K.
- Five pressure/leak test cycles: 1.95 MPa at 77K and at the room temperature.
- High-voltage test No. 2: 5kV – DC, 3.5kV – AC, partial discharge (1.2-1.3 bar, helium).

S/s end-fittings

G10 central rods

Welding procedure

30kV HV IB after cutting



30kV HV IBs in the oven

Cross section of 30kV HV IB

Different stages of production

longitudinal section of 30kV HV IB

Winding inner layer

Winding external layer

TEST RESULTS

Test	Acceptance (4 kV HV IBs/30 kV HV IBs)		4 kV HV IBs (30 units)	30 kV HV IBs (65 units)
Visual inspection (endoscope)	+ (OK)		Not done	+ (OK)
Flow test	≥ 0.4	[m^3/min]	Not done	0.40 ÷ 0.49
Leak tightness at RT (vacuum inside)	< 10^{-9}	[Pa·m^3/s]	3.2 ÷ 9.8 x10^{-10}	2.9 ÷ 9.8 x10^{-10}
Leak test under pressure 1.95/3.9 MPa	< 10^{-9}	[Pa·m^3/s]	0.98 ÷9.8 x10^{-10}	0.96 ÷10 x10^{-10}
High-Voltage test №1 (at 1.2-1.3 bara He):				
- at 5/35 kV – DC	6/15	[μA]	0	0.5 ÷ 5
- at 3.5/25kV – AC	10/100	[μA]	2.5 ÷ 2.9	19 ÷ 45
5 thermal/pressure cycles 300-77K and leak tests:				
- during thermo cycles	< 10^{-9}	[Pa·m^3/s]	0.42 ÷ 0.98 x10^{-10}	0.96 ÷ 9.8 x10^{-10}
- at 77K and 1.95/3.9 MPa	< 10^{-9}	[Pa·m^3/s]	0.04 ÷ 0.82 x10^{-10}	0.01 ÷ 7.3 x10^{-10}
- at 300K and 1.95/3.9 MPa	< 10^{-9}	[Pa·m^3/s]	0.72 ÷ 1.7 x10^{-10}	1.1 ÷ 9.8 x10^{-10}
High-voltage test №2 (at 1.2-1.3 bara He):				
- at 5/35 kV – DC	6/15	[μA]	0	0.5 ÷ 3
- at 3.5/25 kV – AC	10/100	[μA]	2.5 ÷ 2.9	20 ÷ 50

Typical insulation breaks

CONCLUSION

The cryogenic HV insulation breaks with spiral and uniflow channels have been developed to satisfy the requirements of modern large-scale electrophysical equipment involved in the ITER magnet system.
The key feature of the HV IB with spiral channels is the short length coupled with the high level of operating voltage.
To test of the cryogenic HV IBs the special test equipment has been prepared and accepted for operation.
The cryogenic HV IBs have been manufactured and passed the tests required by the ITER Technical Specifications for the axial insulation breaks.
About 4 months were required to manufacture and test 65 units of 30kV HV IBs and 30 units of 4kV HV IBs. Implementation of the contract up to shipment of the last batch took 11 months.

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