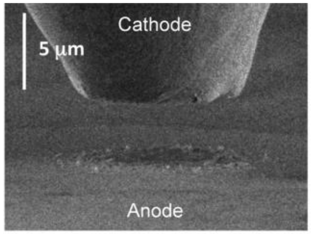

Considerations on HV requirements and impact to test stands

F. Rodriguez Mateos
CERN/TE/MPE/EE

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Outline

- Introduction
- Strategy to define test levels
- Case study: impregnated coils
- General considerations

Introduction

- One of the **main aspects in the design of superconducting circuits** (magnets, leads, links, bus bars) is the monitoring of the **electrical quality and integrity** of the components during manufacturing, tests at stands and further during commissioning
- All circuit components (magnets, bus bars, link, current leads, instrumentation), including also the warm DC distribution elements, have to be **harmonised** in this respect **– GLOBAL APPROACH**
- To this aim, one has to define as soon as possible **the tests and the voltage levels**, in agreement with the equipment owner …

…**and the test stand responsible!**

General strategy

Definition of worst case voltages from quench modeling/model tests

Definition of conditions under which worst case voltages will show up: ambient conditions (gas, liquid), pressure and temperature

Definition of test conditions

Scaling factor ***f***

Definition of strategy:
i) Validation that the worst case voltages will be endured with no degradation and certain margin
ii) Looking for insulation faults

Defining rated and test voltages (1/3)

V_q = quench voltage
V_{ee} = extraction voltage
V_{pa} = power abort voltages
$\mathbf{V_{maxr} = V_q + V_{ee} + V_{pa}}$

Rated level

$\mathbf{V_{rated}} = a * V_{maxr} + b$

a and **b** give safety margins

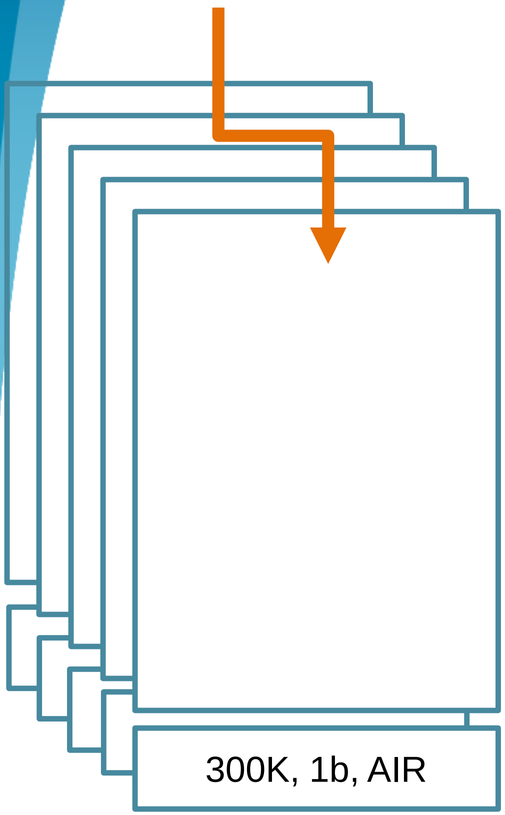
(for LHC : **a**= 2 and **b**= 500 V)

E. g. 75 K, 1 bar , He (gas)

For example purposes, we take as reference 75K and 1 bar in He gas for the conditions at which the maximum voltage occurs

Defining rated and test voltages (2/3)

Manufacturing steps



1st test at arrival to test bench

VmaxrAir = **f2** * Vmaxr

Vtest_Air=
a*VmaxrAir + b

f2 is an equivalence between 75 K He and 300 K air

300 K, 1 bar , AIR

1st test at cold in the test bench

VmaxrLHe = **f3** *
Vmaxr

Vtest_LHe=
a*VmaxrLHe + b

f3 is an equivalence between 75 K and 1.9 K in LHe

1.9 K, 1 bar, He (liquid)

1st test after cold test in air but possibly with He gas

VmaxrAir2 = **f4** *
Vmaxr

Vtest_Air2=
a*VmaxrAir2 (+ b)

f4 is an equivalence between 75 K and 300 K in He

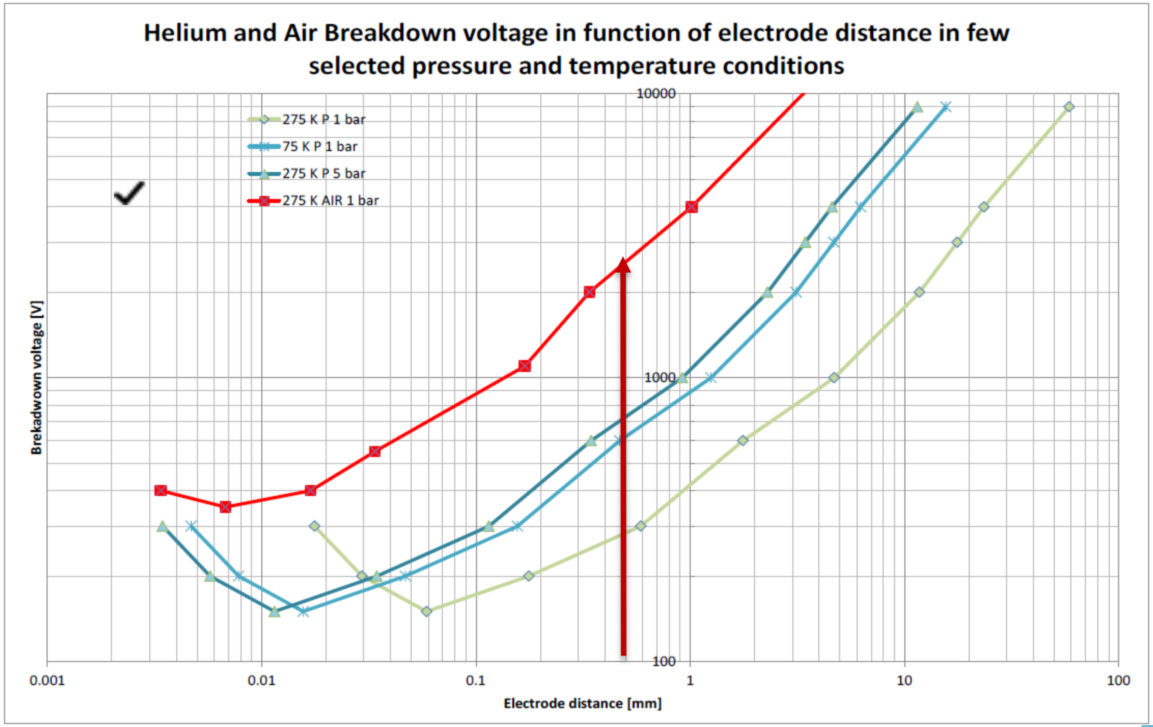
300 K, 1 bar , He (gas)

Factors ***f*** are defined as ratios of dielectric strengths at the two conditions considered

Dielectric strength for 0.5 mm gap

Values in [V]

$V_{Air, 275 K, 1 b}$	2500
$V_{LHe, 4.2 K, 1 b}$	7000
$V_{GHe, 275 K, 5 b}$	700
$V_{GHe, 75K, 1 b}$	600
$V_{GHe, 275 K, 1 b}$	280



f2= 2500/600 = 4.2

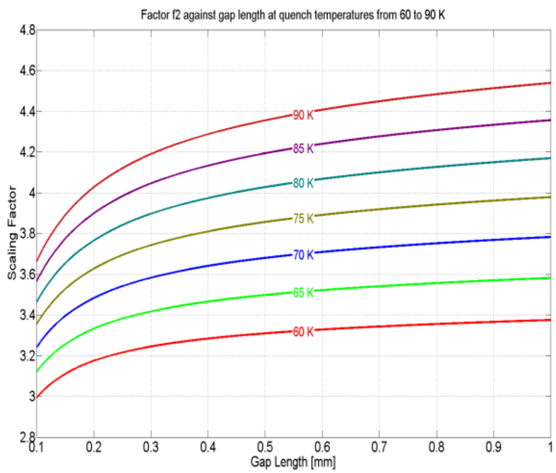
f3= 7000/600 = 11.7

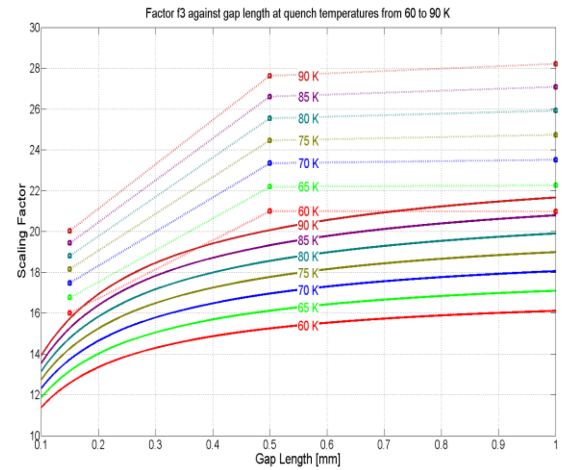
f4= 280/600 = 0.47

Sensitivity analysis

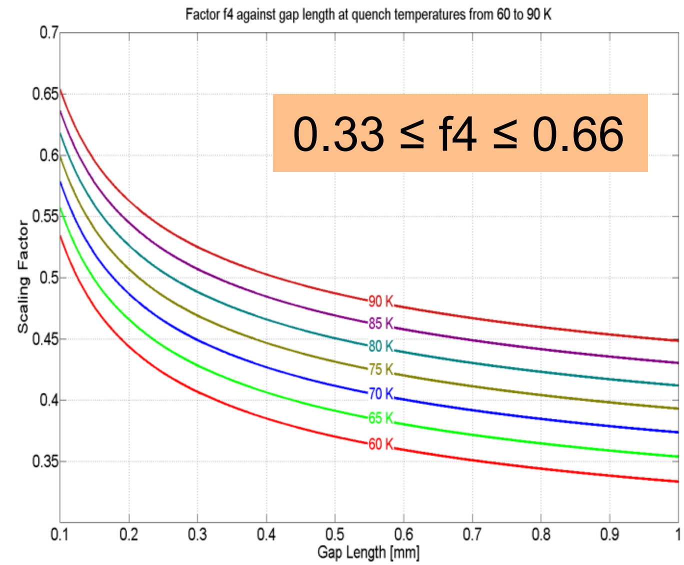
It is assumed that the maximum voltage is reached at temperatures between 60K and 90K

3 ≤ f2 ≤ 4.6





- 11 ≤ f3 ≤ 22 boiling LHe
- 16 ≤ f3 ≤ 29 non-saturated LHe



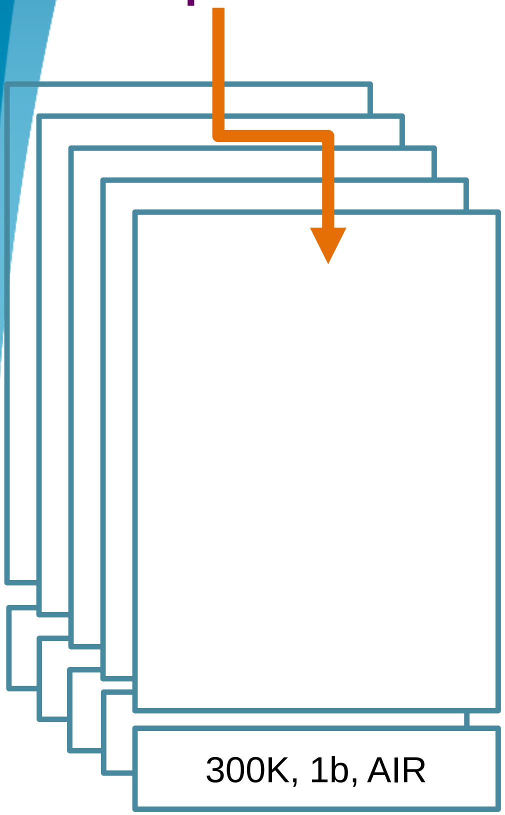
0.33 ≤ f4 ≤ 0.66

Distance between two active parts (e.g. turns of the same layer, turns to heater) or between active parts and ground span from 0.1 to 1 mm in QXF magnet (P. Ferracin)

Courtesy Hugo Bajas and Jose Vicente Lorenzo Gomez TE-MSC

Defining rated and test voltages (3/3)

Manufacturing steps



1st test at arrival to test bench

VmaxrAir = **f2** * Vmaxr

Vtest_Air= a*VmaxrAir + b

f2 is an equivalence between 75 K He and 300 K air

300 K, 1 bar , AIR

1st test at cold in the test bench

VmaxrGHe = **1** * Vmaxr

Vtest_GHe= a*VmaxrLHe + b

75 K, 1 bar, He (gas)

1st test after cold test in air but possibly with He gas

VmaxrAir2 = **f4** * Vmaxr

Vtest_Air2= a*VmaxrAir2 (+ b)

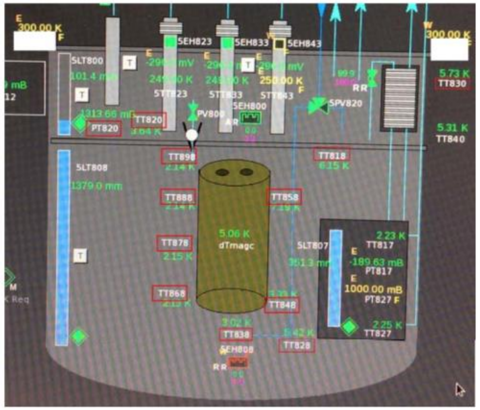
f4 is an equivalence between 75 K and 300 K in He

300 K, 1 bar , He (gas)

If test conditions = worst case voltage conditions

Case study : impregnated coils

- It has been observed during quench tests that for impregnated coils T and p slowly move up after a quench, this would hint towards taking nominal operating conditions as the ones under which worst case voltages appear
- This assumes **no cracks inside the coils**, only global p and T apply



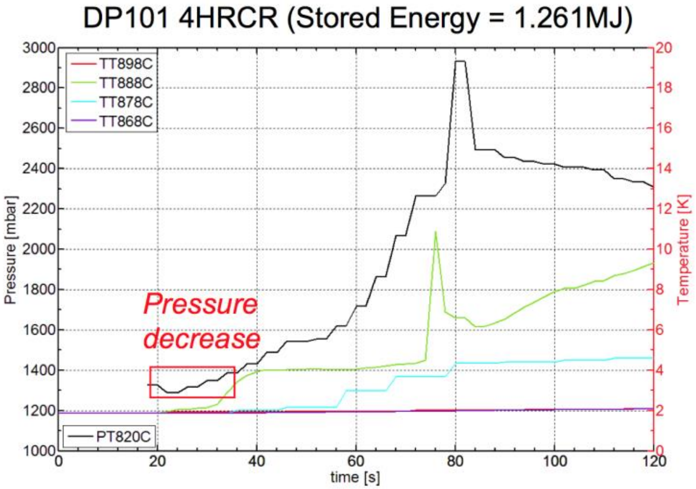


Fig. 1 – (Left) Schematic of the test-rig. (Right) Pressure and measurement evolution during a quench test.

Courtesy Hugo Bajas

Proposed strategy for inner triplet magnets in HL-LHC

- Studies have been conducted through a working group dealing with aspects related to electrical integrity and quality assurance (see HL-LHC HVWL Working Group).
- The main objective of the working group so far has been to find a formal approach in order to obtain high voltage levels from scaling and safety factors obtained starting from simulated worst case voltages (see presentation at the LARP Hi-Lumi Collaboration meeting in May 2016 at SLAC, USA: Voltage Withstand Levels).

Circuit Element	Expected Vmax [V]	V hi-pot	I hi-pot [µA]	Minimum time duration [s]
Coil to Ground at RT *	n.a.	3 kV	10	30
Coil to Quench Heater at RT *	n.a.	4.6 kV	10	30
Coil to Ground at cold **	520	1.5 kV	10	30
Coil to Quench Heater at cold **	900	2.3 kV	10	30

General considerations

- Definitions on withstand levels for test stations are to be done in thorough agreement with the programme established for magnets and other d.u.t. (leads, s.c. link and current leads)
  - What margin to take for the stand w.r.t. test levels?
- Studies initially focus on voltage to ground and voltages coil-to-heaters, but other issues as turn-to-turn insulation test by impulses need to be analyzed
- Decisions on the HV test programme are required well in advance as to make adequate engineering of dielectric strengths at the facility in different conditions:
  - Air (defined temperature and humidity)
  - Nominal, cold conditions
  - Intermediate temperature conditions
  - Different pressure levels
  - Leads disconnected
  - Modified instrumentation

Many thanks for your attention!