“Bushing Cooldown Partial Discharge Test”

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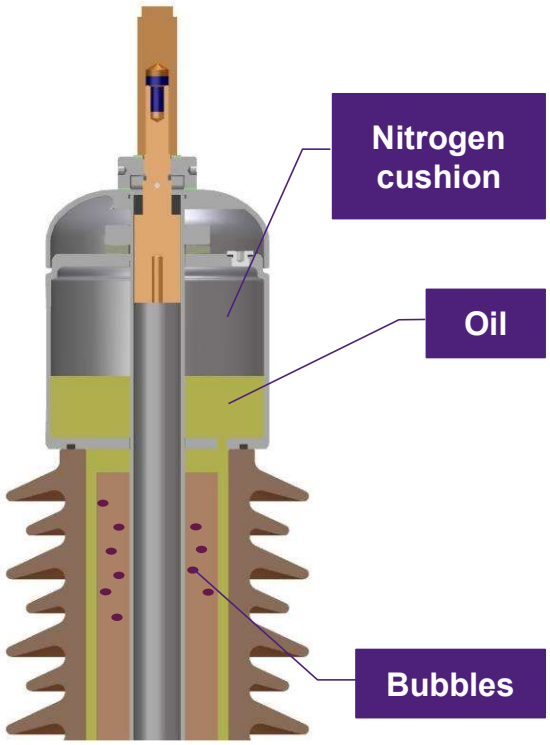
Gas Bubble Evolution in the oil of OIP Bushings



- Gas Bubble Evolution is a known phenomenon that can appear in oil impregnated paper bushings (OIP) of all manufacturers.
- The nitrogen from the Nitrogen Cushion dissolves partially in the oil of the bushing until an equilibrium is reached. When the bushing is heated, the temperature and pressure inside the bushing increase, leading to more nitrogen absorption and a higher gas saturation level. **When the bushing cools down, the gas saturation level reduces. At this stage oversaturation of the oil with gas can occur and gas bubbles can be released to the oil.**
- Gas bubble generation can occur during transformer testing (heat run test followed by cool down of the transformer and bushing). Subsequent electrical tests can lead to PD in the bushing and failure during the dielectric tests.
- Gas bubble generation can also occur in operation as the result of rapidly cooldown of a bushing or due to cyclic loading with/without cyclic variation of ambient temperature and solar radiation ⇒ Sustained PD activity inside the bushing shall be avoided in operation.

Proposal: Define a test procedure which allows to identify if a bushing design tends to produce partial discharge activity due to nitrogen bubbles during the FAT of the transformer.
The test conditions shall be severe enough to avoid sustained partial discharges under service conditions.

Test Principles for the "Bushing Cooldown Partial Discharge Test"

Principle:

1. Put the bushing at a temperature rise to ambient which covers transformer-FAT and operating conditions
2. Wait until the oil of the bushing is saturated with nitrogen
3. Let the bushing cool down at the ambient temperature to create oversaturation of the bushing oil with nitrogen
4. Perform electrical tests of the bushing with measurement of PD activity

Comments:

- Point 1 can be achieved by installing the bushing on a heated oil vessel in a room with controlled temperature. However, for practical reasons it is easier to heat the complete bushing in an oven. This will reduce the time to reach saturation, and ensure a steeper temperature drop of the bushing. Nitrogen saturation can be indirectly monitored by measuring the pressure inside the bushing: a stabilization of pressure corresponds to a stabilization of nitrogen transfer between gas cushion and oil.
- Depending on the design, size, geometry and temperature of the bushing, the time constant for nitrogen dissolution into the oil can be in the range of several days. 99% saturation could potentially take several weeks. Prior storage of the bushing at ambient temperature for a longer time may help to reduce the heating time.
- To account for geometrical tolerances on components, the test should be performed on more than one sample. The proposal is to test 3 samples of a given design.

Temperature Conditions for the Cooldown PD Test

IEEE Std C57.12.00-2021
IEEE Standard for General requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers

5.11.1.5 Liquid temperature rise

The insulating liquid temperature rise above ambient temperature shall not exceed 65 °C when measured near the top of the main tank.

IEEE Std C57.19.00-2004
IEEE Standard General Requirements and Test Procedures for Power Apparatus Bushings

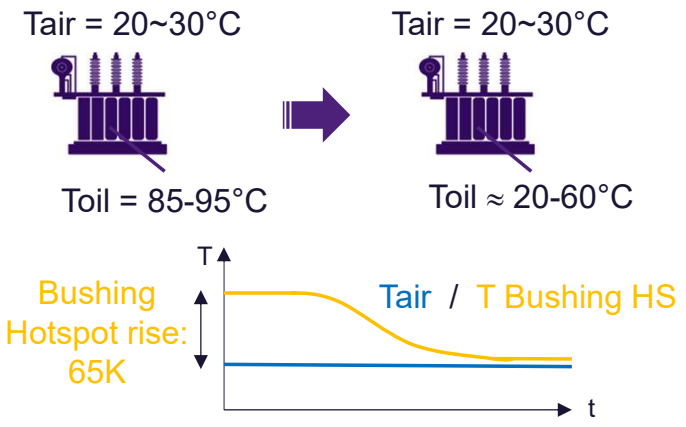
5.4.1 Thermal basis of rating

The hottest-spot temperature rise above ambient air of any part of the bushing in contact with temperature index 105 insulation shall not exceed 75 K, when the inboard end is immersed in oil within 50 mm of the mounting flange with the oil having a rise of 65 K above the ambient air and the bushing is carrying rated current at rated frequency.

- The maximum Hotspot rise of a bushing on a transformer may not be achieved at the maximum load for an ONAN/ONAF cooled transformer. Therefore, the bushing hotspot rise may be in most cases lower than 75K, often in the range of **65K**.

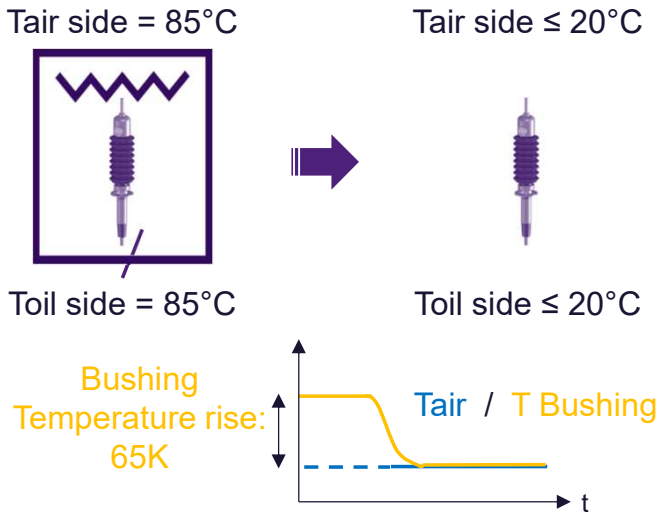
Temperature Conditions for the Cooldown PD Test

Transformer FAT at Rated Load



Transformer Oil Time constant: a **3 to 4h**

Bushing Cooldown before Partial Discharge Test



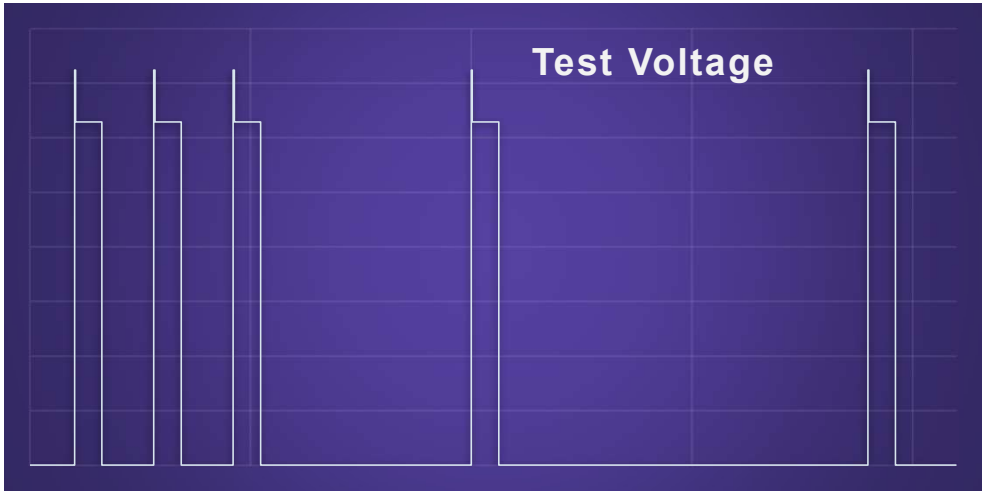
Bushing Time constant: **1 to 2h**

The conditions of the transformer FAT must be covered and overfulfilled during the bushing cooldown test:

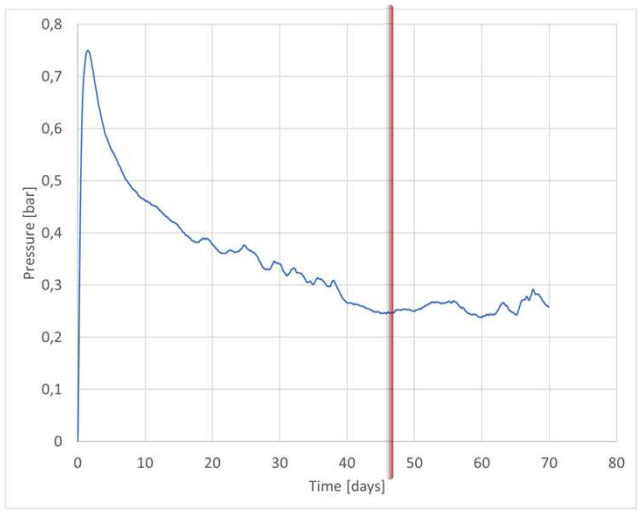
- Same temperature rise of the bushing against ambient as the bushing hotpot rise during the transformer FAT at Imax.
- Assure saturation of the oil with nitrogen before cooldown.
- Cooldown-time to be shorter than the cooldown-time time on the transformer during FAT to compensate the higher N2 saturation during possible overloads during FAT and in service.

Proposed Test Procedure for the Cooldown PD Test

- Each sample is taken out of the oven and let to cool down
- PD measurements are started at beginning of bushing cooldown and are performed at several time instants during a 24 hours period.
- For each measurement step, the electrical test sequence is as per IEEE Std C57.12.00
  - Enhanced level 1.8 x nominal system voltage (line-to-ground) for 7200 cycles
  - 1.58 x nominal system voltage (line-to-ground) for 1 hour
- These electrical values cover the transformer FAT program and assure safe operating conditions.
- The bushing passes the test if there is no PD above 10pC measured during the test sequence.



Example: 230 kV OIP Bushing Cooldown PD Test



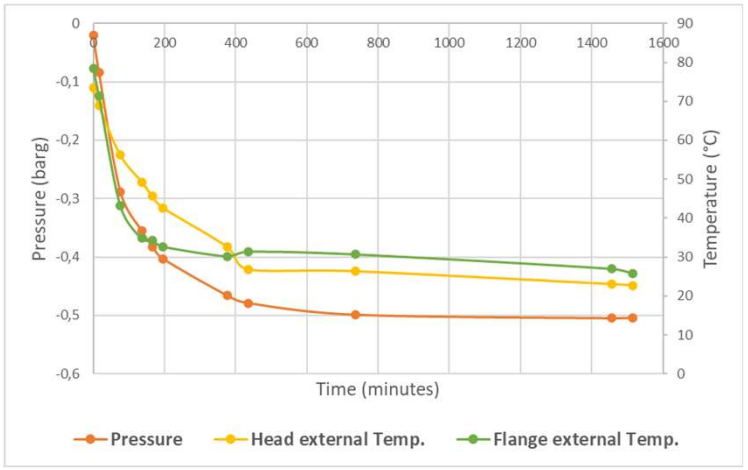
Internal pressure during the saturation phase

Table 1: Report for electrical tests

App. n° : 21B5157						Client Customer				
Tension maximale Highest voltage	230 kV									
Fréquence nominale Rated frequency	60 Hz									
Courant nominal Rated current	800 A					Commande Order	7000296 / 30			
Essai selon Test as to	IEEE C57.19.01-2017					Plan d'encombrement Drawing	41426821 / 07			
Complètement montée / Completely assembled										
partie sup. dans / upper part in: partie inf. dans / lower part in:	☐ Huile/Oil ☒ Air ☐ SF6 ☒ Huile/Oil ☐ Air ☐ SF6								pièteement / turret ☐	
Conditions atmosphériques Atmospheric conditions	1004 mbar 21 °C 84 % humidité relative / relative humidity									
Test conditions: The bushing is heated at 85°C in autoclave until bushing internal pressure is stabilized (including depressurization phase due to nitrogen dissolution into oil). The bushing is removed from the autoclave and installed in the high voltage test field.										
Time		Temperature (°C) Head	Temperature (°C) Flange	Internal Pressure (bar)	Voltage (kV)	PD (pC)	C1 (pF)	PF (%)	PD inception voltage (kV)	PD extinction voltage (kV)
Removal from autoclave										
t_0 =										
Test under voltage										
t_1 =					146	< 1	487	0,42		
t_1 + 15 min					146	< 1	487	0,41		
t_1 + 30 min					146	< 1	487	0,40		
t_1 + 45 min					146	< 1	486	0,37		
t_1 + 60 min					146	< 1	486	0,36		
t_1 + 75 min					146	< 1	486	0,34		
t_1 + 90 min					146	< 1	485	0,33		
t_1 + 105 min					146	< 1	485	0,33		
t_1 + 120 min					146	< 1	485	0,31		
t_1 + 135 min					146	< 1	485	0,31		
t_1 + 150 min					146	< 1	484	0,31		
t_1 + 165 min					146	< 1	484	0,30		
t_1 + 180 min					146	1	484	0,30		
t_1 + 195 min					146	1	484	0,30		
t_1 + 210 min					146	1	484	0,30		
t_1 + 225 min					146	1	483	0,29		
t_1 + 240 min					146	1	483	0,29		
t_1 + 255 min					146	1	483	0,29		
t_1 + 270 min					146	1	483	0,29		
t_1 + 285 min					146	1	483	0,29		
t_1 + 300 min					146	1	483	0,29		

Time		Temperature (°C) Head	Temperature (°C) Flange	Internal Pressure (bar)	Voltage (kV)	PD (pC)	C1 (pF)	PF (%)	PD inception voltage (kV)	PD extinction voltage (kV)
t_1 + 315 min					146	1	483	0,29		
t_1 + 330 min					146	1	483	0,29		
t_1 + 340 min					146	1	483	0,29		
t_1 + 340 min					240 (144 s)	2	483	0,28		
t_1 + 342 min					210 (60 mn)	2	483	0,28		
t_1 + 402 min					146	1	483	0,28		

Example: 230 kV OIP Bushing Cooldown PD Test



Internal pressure and external bushing temperatures during cooldown phase

Table 1: Report for electrical tests

App. n° : 21 B 5156 — Client / Customer

Tension maximale / Highest voltage	230 kV									
Fréquence nominale / Rated frequency	60 Hz									
Courant nominal / Rated current	800 A									
Essai selon / Test as to	IEEE C57.19.01-2017									

Commande / Order: 7000296 / 30

Plan d'encombrement / Drawing: 41426821 / 07

Complètement montée / Completely assembled

partie sup. dans / upper part in: ☐ Huile/Oil ☒ Air ☐ SF6 pièdement / turret

partie inf. dans / lower part in: ☒ Huile/Oil ☐ Air ☐ SF6 ☐

Conditions atmosphériques / Atmospheric conditions: 1011 mbar 19 °C 63 % humidité relative / relative humidity

Test conditions: The bushing is heated at 85°C in autoclave until bushing internal pressure is stabilized (including depressurization phase due to nitrogen dissolution into oil). The bushing is removed from the autoclave and installed in the high voltage test field.

Time		Temperature (°C) Head	Flange	Internal Pressure (bar)	Voltage (kV)	PD (pC)	C1 (pF)	PF (%)	PD inception voltage (kV)	PD extinction voltage (kV)
1. Removal from autoclave										
t_0 =	6H14	73,4	78,4	-0,02	-	-	-	-	-	-
2. Test under voltage										
t_1 =	6H30	68,9	71,4	-0,084	240 (144 s)	<1	487	0,43		
	7H30	56,2	43,2	-0,288	210 (60 mn)	<1	485	0,37		
t_1 + 2 h	8H30	49,3	34,8	-0,355	-	-	-	-	-	-
t_1 + 2,5 h	9H00	45,6	34,3	-0,382	-	-	-	-	-	-
t_1 + 3 h	9H30	42,6	32,7	-0,403	240 (144 s)	<1	484	0,30		
		39,8	32,1	-0,436	210 (60 mn)	<1	483	0,23		
t_1 + 6 h	12H30	32,6	30,2	-0,466	240 (144 s)	<1	482	0,28		
	13H30	26,8	31,4	-0,479	210 (60 mn)	<1	482	0,28		
t_1 + 12 h	18H30	26,3	30,7	-0,499	240 (144 s)	<1	482	0,29		
		26,2	30,5	-0,499	210 (60 mn)	<1	482	0,29		
t_1 + 24 h	6H30	23,0	27,0	-0,505	240 (144 s)	<1	481	0,29		
	7H30	22,7	25,7	-0,504	210 (60 mn)	<1	481	0,29		