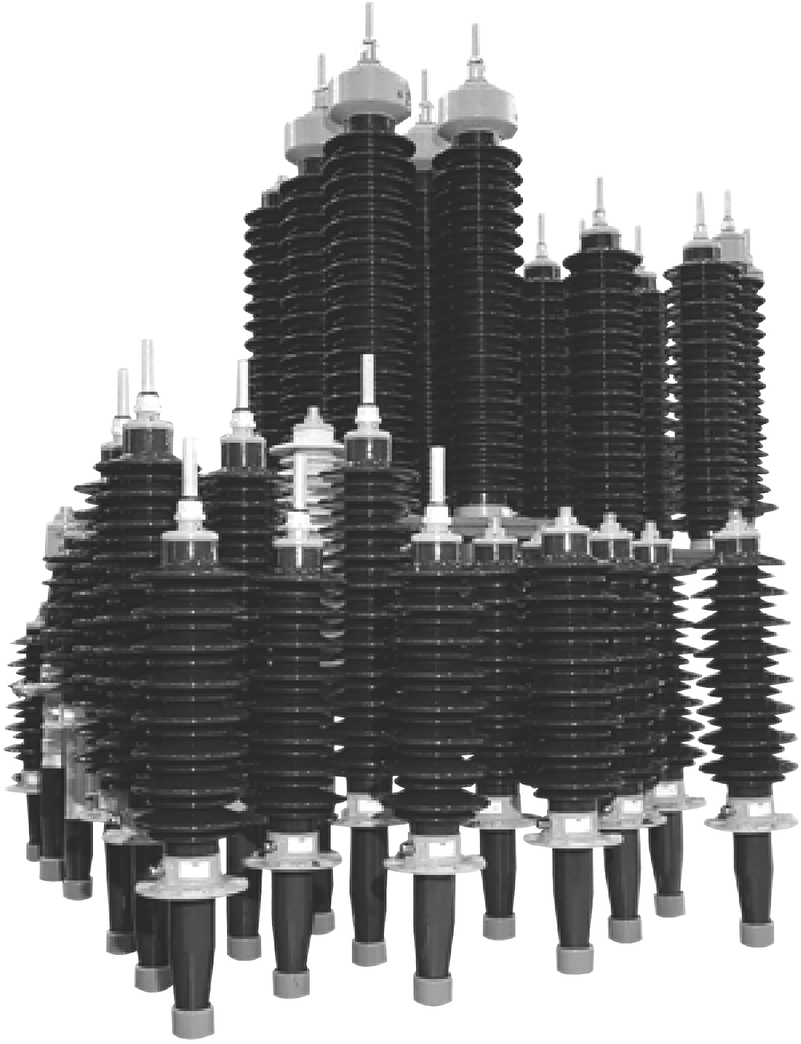
Bushing diagnostics and conditioning

Product information



ABB

Safety information

Keep this instruction available to those responsible for the installation, maintenance, and operation of the bushing.

The installation, operation, and maintenance of a bushing present numerous potential unsafe conditions, including, but not limited to, the following:

- High pressures
- Lethal voltages
- Moving machinery
- Heavy components
- Slip, stumble or fall

Specialized procedures and instructions are required and must be adhered to when working on such apparatus. Failure to follow the instructions could result in severe personal injury, death, and/or product or property damage.

Additionally, all applicable safety procedures such as regional or local safety rules and regulations, safe working practices, and good judgement must be used by the personnel when installing, operating, maintaining and/or disposing such equipment.

Safety, as defined in this instruction, involves two conditions:

1. Personal injury or death.
2. Product or property damage (includes damage to the bushing or other property, and reduced bushing life).

Safety notations are intended to alert personnel of possible personal injury, death or property damage. They have been inserted in the instructional text prior to the step in which the condition is cited.

The safety conditions are headed by one of the three hazard intensity levels which are defined as follows:

DANGER

Immediate hazard which will result in severe personal injury, death, or property damage.

WARNING

Hazard or unsafe practice which could result in severe personal injury, death, or property damage.

CAUTION: *Hazard or unsafe practice which could result in minor personal injury, or property damage.*

Contents

1 General guide to diagnostics and conditioning of bushings

In the following document guidelines for diagnostics and conditioning of bushings are available. The document is mainly based on the experience for diagnostics and conditioning available at ABB Components. Utilities and the test-equipment producers have much practical knowledge for the job described in this document. Combining the great knowledge at utilities, test-equipment producers and the product knowledge from ABB Components, as written in this document, will lead to the best possible interpretation of the bushing condition.

2 Diagnostics

There are several methods for diagnostics of high voltage bushings available. In general bushings delivered from ABB Components shall be considered maintenance free. However inspection and service experience will in some cases lead to diagnostics on bushings.

In the following chapters a guide for different test methods and interpretations are available. Some methods are today not widely commercial available for site diagnostics. In this document they are therefore briefly described.

2.1 Capacitance and tan δ measurement

WARNING

Make sure that the transformer is de-energized and out of service before any work is performed on the bushing.

The test tap must not be left open during service. Check that the earthing spring and the protective cap is put in position after test. The test tap design is shown in the installation and maintenance guides.

The testing equipment must not be connected to the test object before the transformer is de-energized and taken out of service. All windings shall be short-circuited, and windings not connected to bushings under test shall be grounded.

Prior to taking a condenser bushing into service, and on a suspected fault, the capacitance and dissipation factor can be measured and compared with the values given on the rating plate or in the routine test report. In connection with these tests, the electrical connection between transformer tank and bushing flange shall be checked for instance with a buzzer.

In this product information, the terms tangent delta, tan δ, power factor and dissipation factor can be used interchangeably.

2.1.1 Test equipment

Measuring bridge:
The measuring bridge shall be of transformer-ratio arm type. Bridges of this type are available in several designs from various manufacturers. Examples of measuring bridges:

Manufacturer	*Model*	
Doble Engineering Company	M2H	
Tettex Instruments	2088	
Tettex Instruments	2805	Can be used at good interference conditions
Multi-Amp Corporation	CB-100	For low voltage only (30 V)

Regarding the handling of the bridge, the manufacturer’s manual shall be consulted. For connecting the measuring lead to the test tap, a special adapter must be used for certain bushings. This device is described in the product information for each type of bushing.

Voltage source:
When measuring the dissipation factor, a voltage source must be available, either separate or built into the measuring equipment. The voltage should be adjustable up to at least 10 kV, and as far as possible free from harmonics. To avoid problems when adjusting the null indicator, the voltage ought to be synchronous with the voltage in the plant.

Measuring using digital instruments:
If only the main capacitance C_1, is to be measured, and an accuracy of ±3 % is accepted, a simpler method can be used. The method, described later, only requires a voltage source of 400 V/2 A, two digital instruments and a 10 kW/10 W resistor.

2.1.2 Measuring procedure

When testing a bushing having a capacitive test tap, i.e. practically all our bushings, it is not necessary to disconnect the top of the bushing. It is enough to open the disconnecting switch.

For the sake of safety and for reduction of the influence from the winding inductance, all transformer windings shall be short-circuited. Windings not connected to the tested bushing shall be grounded. See Fig. 1.

The bridge shall be placed on a vibration-free base. If the reference capacitor is separate, it shall be placed on a dry, insulating base.

Depending on which insulation is to be tested, the voltage source (test voltage) shall be connected via separate leads to the bushing top or the capacitive test tap. Leads for test voltage or grounding must not be common with leads for measuring. Measuring leads shall be as short as possible and must not touch grounded objects. Bands or strings used for spacing must be dry and clean. This also applies to the test object. If the bushing is in its transport case, it must not be surrounded by wet filling material. The test tap shall be clean and dry.

At humid conditions drying of the test tap may be required in order to get representative readings for tan δ over C_2. An air dryer may be used for drying. Cleaning of the air side insulator housing is indispensable for correct measurement of tan δ over C_1.

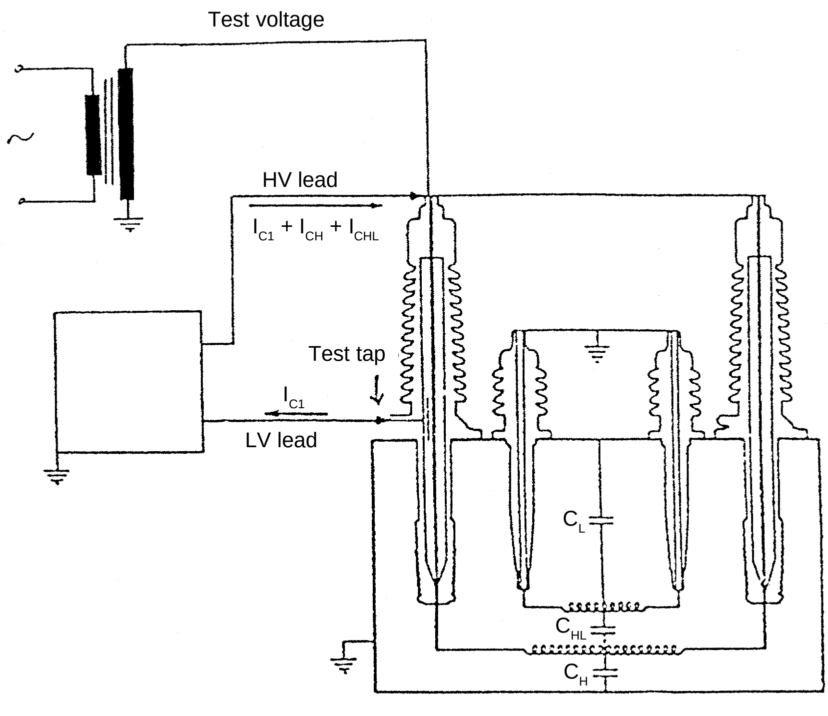


Fig. 1. Field testing on bushings using the UST method (Ungrounded Specimen Test).

2.1.2.1 Dissipation factor test

It is assumed that the bushing to be tested is equipped with a capacitive test tap. It is further assumed that the bridge in use can measure ungrounded, according to the UST-method (Ungrounded Specimen Test). This way, the influence from the transformer on the test result (tan δ) is minimized. The test shall be carried out at highest possible temperature.

The ground terminal on the bridge shall be connected to the ground terminal on the transformer. When measuring an unmounted bushing, the flange shall be grounded. To make it possible to compare the test result with the value on the rating plate or with the routine test report supplied with each bushing, the dissipation factor shall be measured at 10 kV.

The measurement procedure shall begin with a low sensitivity on the bridge. The sensitivity is then increased gradually to the highest possible. In rare cases, external interferences can make it difficult to set the detector to zero. If the interference cannot be eliminated, the sensitivity must be lowered. Table 1 shows the connections to be made, when measuring the dissipation factor of the different insulations. It is to be noted that most bridges give capacitance and dissipation factor in the same measuring operation.

Table 1. Connections for different measurements. Here with the nomenclature of Doble Engineering.

Test sequence						
Test	**Level**	**Voltage to**	**HV test lead to**	**LV test lead to**	**Switch position**	**Measure tan δ and capacitance in**
1	10	CL	CL	Tap	UST	C_1
2	Note A	Tap	Tap	CL	Ground (GST)	$C_1 + C_2$
3	Note A	Tap	Tap	CL	Guard	C_2
4	Note A	Tap	Tap	CL	UST	C_1
5	10	CL	CL	Ground (Flange)	Ground (GST)	The whole bushing

CL = Center conductor
Tap = Capacitive test tap
C_1 = Main insulation
C_2 = Tap insulation
UST = Ungrounded measurement (Ungrounded Specimen Test)
GST = Grounded measurement (Grounded Specimen Test)
Guard = In this position C_1 is by-passed and only C_2 is measured. This method is not available on all bridges.
Note A = Test 2, 3 and 4 shall be carried out at no higher voltage than 500 V if the test tap insulation is delivery tested with 2 kV. If the test tap is tested with 20 kV, 2.5 or 5 kV may be used.

It is recommended to always carry out Test 1. Test 2 should also be carried out, especially if Test 1 gives a deviating result. The capacitance C_2 can be calculated by subtracting C_1. Test 3 and 4 are investigative tests if the previous tests give a suspicion about fault. The dissipation factor, measured at Test 4, should be compared with the values measured at Test 1. Test 5 together with Test 1 and 2, are recommended on unmounted bushings.

Temperature correction:
The measured tan δ value shall be temperature corrected according to correction factor given in Table 2. GOx stands for all oil-impregnated paper condenser bushings (OIP) and GSx stands for resin-impregnated paper condenser bushings (RIP), for all bushings it shall be assumed that the bushing has the same temperature as the top oil of the transformer. The test should be performed at a temperature as high as possible. Correction shall be made to 20 °C. The corrected dissipation factor (tan δ) shall be compared with the value on the rating plate or in the test report.

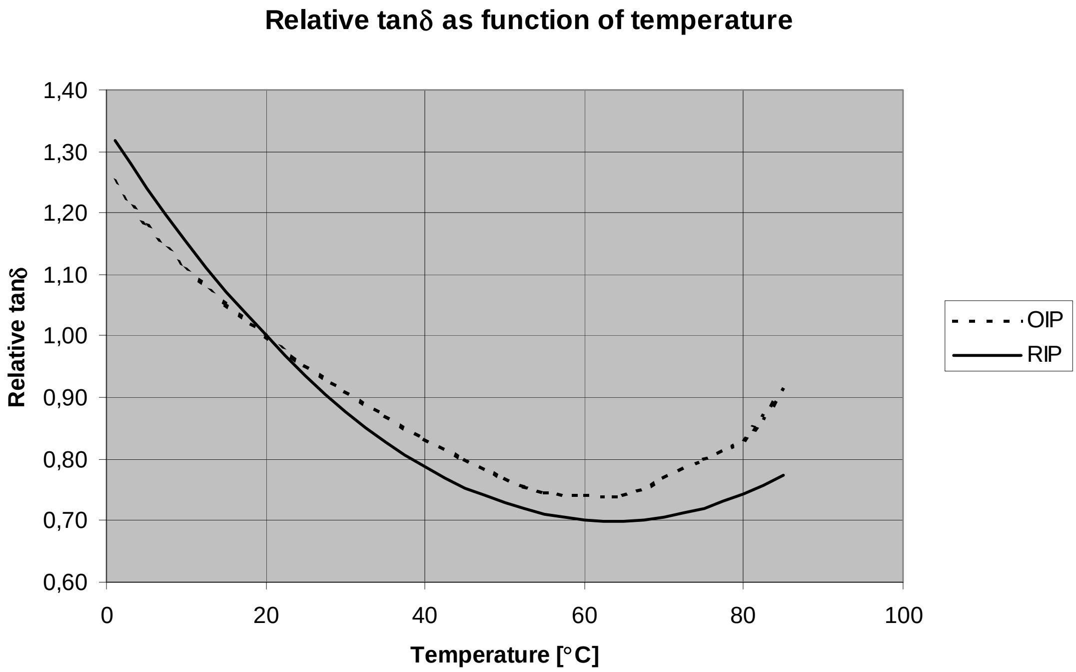


Table 2. Correction factors for tan δ

Range °C	**Correction to 20 °C OIP**	**Correction to 20 °C RIP**
0-2	0.80	0.76
3-7	0.85	0.81
8-12	0.90	0.87
13-17	0.95	0.93
18-22	1.00	1.00
23-27	1.05	1.07
28-32	1.10	1.14
33-37	1.15	1.21
38-42	1.20	1.27
43-47	1.25	1.33
48-52	1.30	1.37
53-57	1.34	1.41
58-62	1.35	1.43
63-67	1.35	1.43
68-72	1.30	1.42
73-77	1.25	1.39
78-82	1.20	1.35
83-87	1.10	1.29

2.1.2.2 Capacitance test

Capacitance test using a bridge:
Fig. 2 shows the principle of the capacitance measurement.

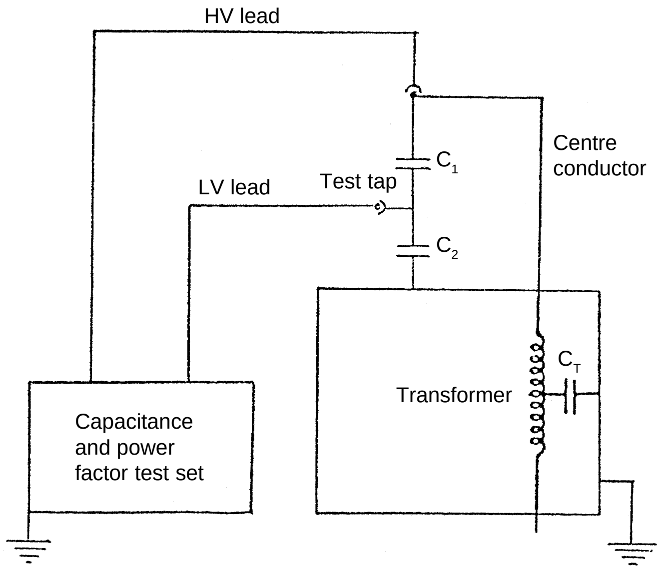


Fig. 2. Principal diagram for capacitance test on bushings, mounted on transformer.

The measurement shall be carried out according to applicable parts of Table 1.
The transformer capacitance C_T to ground may have an influence on the measurement. In most cases this capacitance is small and normally gives a negligible error. However, a deviation between the individual bushings on all three phases may indicate influence from the transformer.

Capacitance test using digital instruments:
This method may give a relatively large measuring error (approx. ±3%) and can be used only for measuring of the main capacitance C_1. However, the disturbance sensitivity is less than for the bridge method, and possible influence from the transformer capacitance is eliminated.

The test circuit is shown on the principal diagram in Fig. 3.

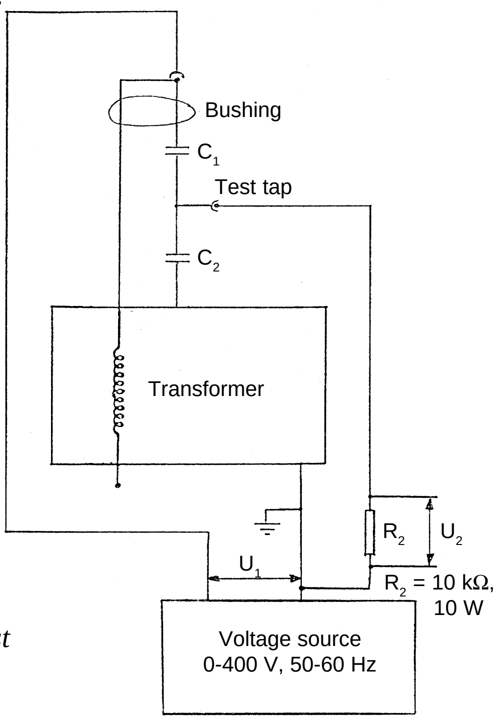


Fig. 3. Principal diagram for capacitance test using digital instruments.

The electrical connection of the resistors R_2 must be good. The opposite terminal N of the transformer winding may be left open or grounded. If it is left open, it will take the same voltage as the top of the bushing. If grounded, the voltage source may be overloaded.

For measuring the voltage U_1 and U_2 digital instruments of type Fluke 8020 or equivalent may be used. It should be noted that digital instruments do not work satisfactory at temperatures below 0C. At temperatures below 0C the instrument must be heated.

Increase the voltage U_1 of the voltage source until U_2 reaches not less than 100 mV_{rms}. U_1 might then be between 200 and 400 V_{rms}. Read U_1 and U_2 and calculate the capacitance C_1 according to the formula below.

$C_1 = U_2/U_1 \text{ x } 1/(R_2 \text{ x } 2pf)$ [F]f = frequency [Hz]

<u>At 50 Hz</u>
$C_1 = U_2/U_1 \text{ x } 318$ [pF] U_2 [mV], U_1 [V], $R_2 = 10$ [kW]

<u>At 60 Hz</u>
$C_1 = U_2/U_1 \text{ x } 265$ [pF] U_2 [mV], U_1 [V], $R_2 = 10$ [kW]

2.1.3 Interpretation of the measurement

Coments on dissipation factor OIP bushings:
The dissipation factor is a critical property in an oil filled condenser core bushing. It is mainly determined by the moisture level in the paper and the amount of contaminants in the insulation system. Together with that, the power factor is also very much dependent on the temperature. The principal behaviour is shown in Fig. 4 below for different temperatures and different moisture levels.

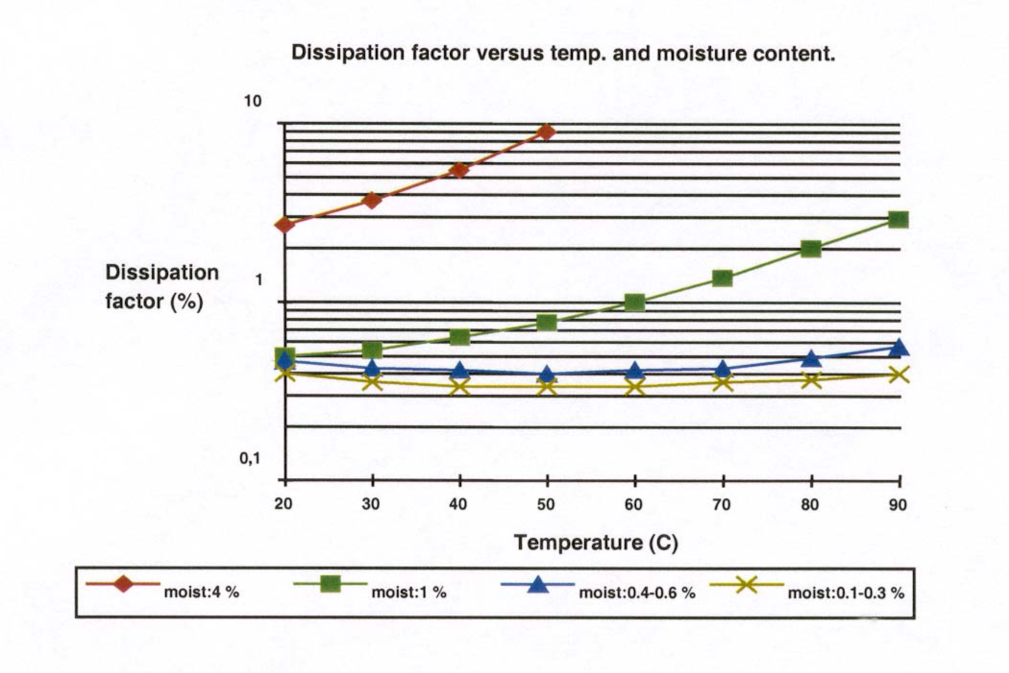


Fig. 4. Tan δ as a function of moisture level and temperature on OIP bushings.

It is clearly visible that the measurements at elevated temperature are more sensitive. At 20 °C moisture levels between 0.1 % to 1 % show about the same dissipation factor. At elevated temperature (90 °C) they differ by a factor of 5 or more. The conclusion from that is that the important property is the dissipation factor at elevated temperature and not the dissipation factor at 20 °C. For bushing, the important factors regarding dissipation factor are:

1) A dissipation factor which is constant with temperature during the entire bushing life.

2) A dissipation factor which remains constant during the entire bushing life.

For the manufacturer of a condenser core bushing, the aim is to reach the right dissipation factor. The contribution to the dissipation factor from contaminants is avoided by a proper material control as well as by high cleanliness requirements in the workshop. The moisture content in the bushing is determined by the winding technique and the drying process of the condenser core.

The standard procedure in making bushings is to wind the condenser core with the paper as such without any drying. This gives a moisture content in the final condenser core of about 4-8 %. The core is then dried in a separate drying process consisting of heat and vacuum until sufficient dryness is reached. Since the water goes out axially there is a need to dry the core very carefully to make sure that no water is trapped in the centre of the core. At the manufacturing of our bushings we dry the paper at the same time as we wind the condenser core. By doing this we get a totally dry condenser core after the winding and a separate drying process is no longer needed. The benefit is that no moisture is trapped in the centre of the core. Together with that we also limit the drying time which means minimum ageing of the paper.

Both ANSI and IEC bushing standards require measurement of the dissipation factor at room temperature as a routine test on new bushings. This is done on all our bushings. During the normal routine test we have requirements for not only the level of the dissipation factor but also the change with voltage since this might be an important sign of contamination in the bushing. Beside that, we take a bushing from ordinary production every second month and place it in a 90 °C oven. After 24 hours the dissipation factor is measured. Our internal instruction requires the value to meet the same requirements as at 20 °C.

During the last 25 years ABB Components have been using only pure cellulose together with aluminium foils and insulation oil in our condenser cores. Through experience, we have seen that the dissipation factor remains totally constant over the years. It is known from the literature that different kinds of glues have caused problems with ageing and with rising dissipation factor as a consequence. The fact that we are using “pure raw materials”, a well controlled process and careful testing combined with our long service experience give us confidence that the tan δ level for our bushings will remain constant during the entire bushing life.

Coments on dissipation factor RIP bushings:
When measuring tan δ on RIP bushings before the bushing is put into service, deviation of the tan δ value compared to the value on the marking plate might appear. The reason for this is most probably moist penetration into the surface layer of the RIP. For instance, this can occur if the bushing is stored without its protective sealed bag, allowing air with high humidity to penetrate the outer surface layer of the bushing.

Normally the tan δ value will decrease into its initial, marking plate value if the bushing is stored indoors in controlled humidity for a week. If the transformer is energized with the bushing in service, the value will decrease within a couple of hours.

Please read and follow the suggested measures in the succeeding section:

Measures for different temperature corrected values OIP and RIP bushings:
0-25% increase:
The value is taken to the record. No further measures are to be taken.

25-40% increase:
The measuring circuit is checked regarding leakage and external interferences. External interference can for instance be influence from nearby current carrying equipment and bus bars. If the difference remains, the gaskets of the oil level plugs are replaced (moisture) according to the product information for the bushing. The measured value is entered in the record, and the bushing can be taken into service.

40-75% increase:
Measures as above and the measurement shall be repeated within one month.

More than 75% increase:
The bushing shall be taken out of service. However, if the dissipation factor is less than 0.4 %, the bushing may be taken into service even if the increase in percentage from a low initial value is greater than 75 %.

Comments on power factor measurements between the tets tap and the mounting flange on OIP and RIP bushings:
Some of our customers do also want to use the capacitance (C_2) and the dissipation factor over the tap insulation as a diagnostic tool. Based on our experience we will strongly recommend to avoid that. There are several reasons to not use those values as diagnostic tools.

- Primarily this dissipation factor is specified to be less than 5 % according to IEC 137. This means that unless other specified no attention is paid to decrease that value to the same level as for the dissipation factor over the main insulation.

- The test tap is connected to the outer earthed layer on the condenser body. The solid layer outside the earthed layer contain an adhesive together with cellulose to make the condenser body more stable. This means that the contribution to the dissipation factor from that part differ from the pure cellulose in the main insulation. It also means that this part can not be used for diagnostic purposes as the adhesive affect the dissipation factor different on different bushings.

It shall be pin-pointed that during operation condition, the outer layer is earthed. Consequently, the insulation between the outer layer and the mounting flange are not subjected to an electrical field and do thereby not cause any dielectric heat losses.
It is likely that if the bushing is placed in contaminated areas, contaminants on the outside of the test tap affect the results. Moisture around the test tap do also affect the measurement.

It shall be pointed out that if the test voltage (500 V if the test-tap insulation is delivery tested with 2 kV and 2.5 to 5 kV if the test tap is delivery tested with 20 kV) is exceeded partial discharge may occur in the region of the test tap which also will affect the measurement.

- Taking all the variations above into account tan delta over the test tap insulation use to vary between 0.4-3.0 %.

Capacitance:
The measured capacitance C_1 shall be compared with the value given on the rating plate of the bushing or with the 10 kV routine test report. If an increase of more than 3 % (which could indicate partial puncture) compared to the factory measured value or an extremely low value (disruption) is measured, please contact ABB Components. A disruption (low C_1) may indicate a transport damage, and the bushing must not be taken into service. C_2 is influenced by the way the bushing is mounted onto the transformer and should not be used for diagnostics.

2.2 Partial Discharge measurements

Partial discharge measurement is primary used at routine testing method. Partial discharge may indicate external corona or internal insulation failures. Used for diagnostic on installed transformers or wall bushings it will show the sum of the partial discharges in the bushing and transformer insulation. External discharges in switchyards may be suppressed by use of external connected measuring coils. By use of new developed acoustic sensors partial discharges may be located. This method requires skilled people doing the measurement and also knowledge by bushing and transformer design.

2.3 Dissolved Gas Analysis (DGA)

WARNING

Make sure that the transformer is de-energized and out of service before any work is performed on the bushing.

This method for diagnostics can only be used on liquid filled bushings e.g. GOx types. Normally we do not recommend our customers to take oil samples from our bushings. The bushing is sealed and tightness tested at the time for the manufacturing. An oil sampling means that the bushing has to be opened. Thus, it is also a risk for improper sealing after the sampling is finished.

However, when a problem is known, for example high power factor over C_1, there might be a need for oil sampling and gas analysis.

2.3.1 Oil sampling from bushing

Oil samples shall preferable be taken during dry weather conditions. If, by some urgent reason, the sample is taken at any other condition the following shall be taken into account:

- Dry and clean the area around the sampling plug carefully before the sampling.
- Protect the area around the sampling plug from rain.

The internal pressure of the bushing must not be altered before and after the sampling as the bushing is supposed to work within a specified interval. This is satisfied if the sample is taken out when the bushing mean temperature is between 0 °C and 30 °C.

The time when the bushing is unsealed shall be as short as possible. Flushing with dry air or nitrogen is normally not necessary.

The oil removed from the bushing shall always be replaced by the same volume of new transformer oil. The new oil shall comply to IEC 296, class II and shall be clean and dry.

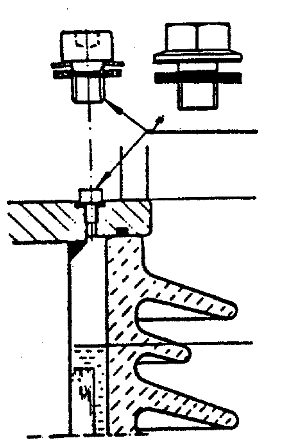
The old gasket shall always be replaced by a new one when the bushing is sealed after sampling.

Sampling procedure for GOB, GOE and GOH
The sample is taken from a plug in the top of the bushing, preferably with a syringe with a rubber hose connected to the top of the syringe.

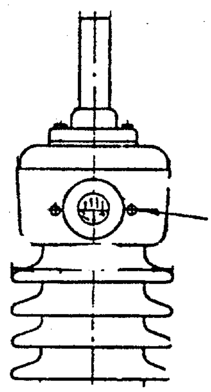
The location for the sampling plug is given in Fig. 5. The dimension of the gasket is given in Table 3. The material of the gasket shall be nitrile rubber (resistant to transformer oil), with a hardness of 70 shore.

The tightening torque for the M8 sealing plug on GOB, GOE and GOH shall be 20 Nm.

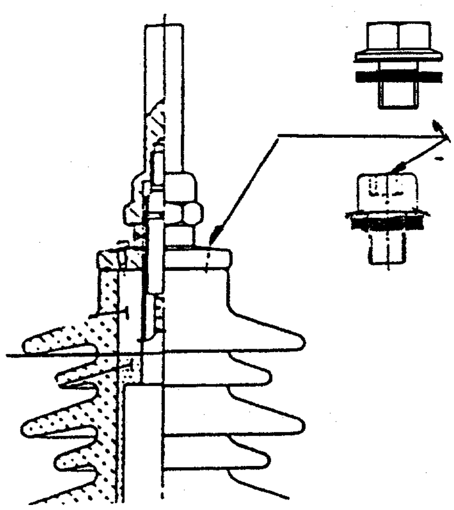
The tightening torque for the M16 sealing plug on GOE shall be 50 Nm.



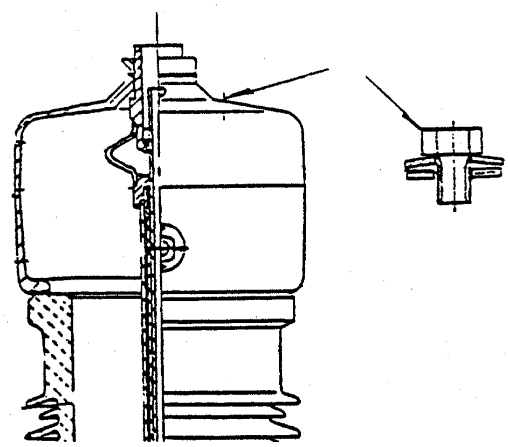
GOH



GOA, GOC and GOG



GOB



GOE

Fig. 5. Location of sampling plugs for GOA, GOB, GOC, GOE, GOH and GOG.

Table 3. Dimensions for gaskets.

Gasket	d (mm)	D (mm)	T (mm)
M8	8	16	3
M16	14	35	4
5/8"	14	35	4

Sampling procedure for GOEK, GOM and other bushings with sampling valve on the flange:
Connect the end of the hose to a suitable nipple and connect the nipple to the valve on the flange. The thread in the valve is (R 1/4") BSPT 1/4". Suck out the oil. Depending on the temperature the pressure inside the bushing might be above or below atmospheric pressure. After the sampling is finished the bushing shall not be energized within 12 hours.

Sampling procedure for GOA, GOC and GOG:
On the GOA, GOC and GOG bushings the oil samples are taken from the hole for the oil level plug on the top housing according to Fig. 5. If the bushing is vertically mounted the oil level is right at the plug level at 20 °C. The sample is sucked out by a syringe. If the oil temperature is slightly higher than 20 °C the oil level will be above the plug level. In such a case the hose on the syringe should be equipped with nipple according to
Fig. 6. The oil plug is removed and the hose with the nipple is attached immediately. If the temperature is slightly below 20 °C, the oil level will be below the plug and the sample is sucked out according to Fig. 7. The tightening torque for the 5/8" sealing plug shall be 50 Nm.

2.3.2 Interpretation of the analysis

The interpretation of the analysis is done according to Technical Report **IEC61464**. If questions remains, ABB Components can assist with the evaluation.

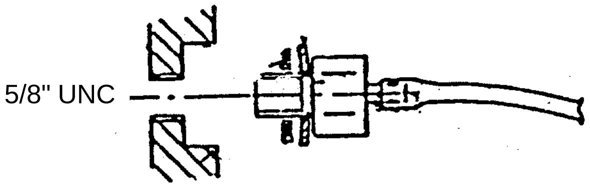


Fig. 6. Sampling on GOA at T > 20 °C.

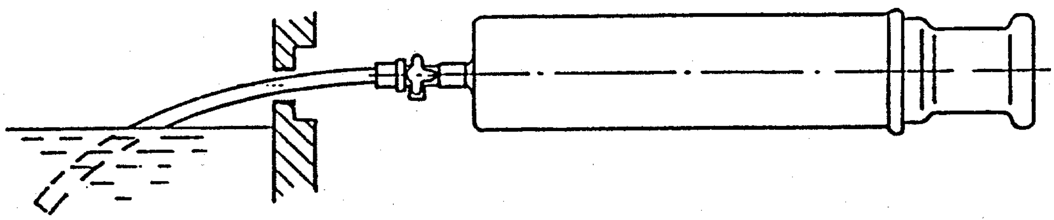


Fig. 7. Sampling on GOA at T < 20 °C.

2.4 Moisture analysis

WARNING

Make sure that the transformer is de-energized and out of service before any work is performed on the bushing.

This method for diagnostics can only be used on liquid filled bushings e.g. GOx types. Normally we do not recommend our customers to take oil samples from our bushings. The bushing is sealed and tightness tested at the time for the manufacturing. An oil sampling means that the bushing has to be opened. Thus, it is also a risk for improper sealing after the sampling is finished.

However, when a problem is known, for example high power factor over C_1, there might be a need for oil sampling and moisture analysis.

To get the proper moisture content in bushing oil is sometimes difficult. Compared to a transformer, a bushing has a much higher ration of paper to oil. This means that regardless of the bushing manufacturing process, there will always be much more moisture in the paper than in the oil. (In paper the moisture is measured in %, whereas in oil the moisture content is measured in ppm, "parts per million".)

Depending on the temperature of the bushing, the moisture will move from the paper to the oil or from the oil to the paper, all given by the equilibrium curves (piper diagram) on oil-paper moisture. Due to this, a bushing will always show a much higher moisture content in the oil after a certain time in service a high temperature. Consequently, to get a proper value, the oil sample should be taken at least 48 hours after the entire bushing has reached room temperature.

2.4.1 Oil sampling from bushing

The oil sampling is performed similar as for DGA analysis.

2.4.2 Interpretation of the analysis

The bushing is delivered from ABB Components with a moisture content in the insulating oil of maximum 3 ppm. If considerably higher concentrations are measured the sealing system is damaged on the bushing.

At a concentration >10 ppm a tan d measurement shall be performed according to section 2.1.2. Measures shall be taken according to the recommendation in section 2.1.3. At a concentration > 20 ppm the bushing shall be taken out of service.

2.5 Oil leakage inspection

WARNING

Make sure that the transformer is de-energized and out of service before any work is performed on the bushing.

A visual inspection for leakage may be performed at normal station supervision.

2.6 Insulator inspection

2.6.1 Hydrophobicity classification

WARNING

Make sure that the transformer is de-energized and out of service before any work is performed on the bushing.

The following information for hydrophobisity calssification is with minor changes taken from STRI AB, Guide 1, 92/1 Hydrofobicity Classification Guide. STRI AB is an independent company for development and testing in the field of electrical power transmission and distribution. STRI is jointly owned by ABB, Svenska Kraftnät (the Swedish National Grid), Vattenfall AB and Statnett SF (the Norwegian National Grid).

2.6.1.1 General

The superior electrical performance of composite insulators and coated insulators stems from the hydrophobicity (water-repellency) of their surfaces. The hydrophobicity will change with time due to exposure to the outdoor environment and partial discharges (corona).

Seven classes of the hydrophobicity (HC 1-7) have been defined. HC 1 corresponds to a completely hydrophobic (water-repellent) surface and HC 7 to a completely hydrophilic (easily wetted) surface.

These classes provide a coarse value of the wetting status and are particulary suitable for a fast and easy check of insulators in the field.

2.6.1.2 Test equipment

The only equipment needed is a common spray bottle which can produce a fine mist (Fig. 8). The spray bottle is filled with tap water. The water shall not contain any chemicals, as detergents, tensides, solvents.

Complementary equipment which could facilitate the judgement are a magnification glass, a lamp, and a measuring-tape.

Fig. 8. Example of a suitable spray bottle for the test.

2.6.1.3 Test procedure

The test area should be 50-100 cm^2. If this requirement could not be met it should be noted in the test report.

Squeeze 1-2 times per second from a distance of 25 ±10 cm. The spraying shall continue for 20-30 seconds. The judgement of the hydrophobicity class shall be performed within 10 seconds after the spraying has been finished.

The hydrophobicity classification could be difficult to perform in high winds. If such difficulties, or other, are present this should be noted in the test report.

2.6.1.4 Classification of the hydrofobicity

The actual wetting appearance on the insulator has to be identified with one of the seven hydrophobicity classes (HC), which is a value between 1 and 7. The criteria for the different classes are given in Table 4. Typical photos of surfaces with different wetting properties are shown in Fig. 10.

Also the contact angle (θ) between the water drops and the surface must be taken into account. The contact angle is defined in Fig. 9. There exist two different contact angles, the advancing contact angle (θ_a) and the receding contact angle (θ_r). A drop exhibits these angles on an inclined surface.

The receding angle is the most important when the wetting properties of an insulator shall be evaluated. The inclination angle of the surface affects the θ_r.

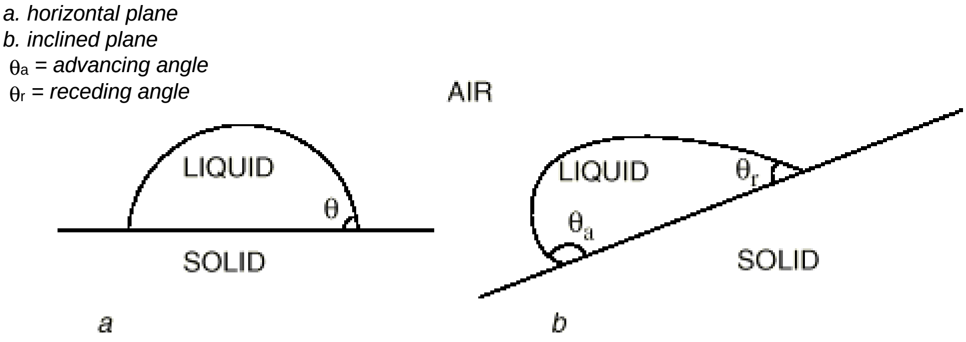


Fig. 9. Definition of contact angles.

Table 4. Criteria for the hydrophobicity classification (HC).

HC	Description
1	Only discrete droplets are formed. θ_r » 80° or larger for the majority of droplets.
2	Only discrete droplets are formed. 50° < θ_r < 80° for the majority of droplets.
3	Only discrete droplets are formed. 20° < θ_r < 50° for the majority of droplets. Usually they are no longer circular.
4	Both discrete droplets and wetted traces from the water runnels are observed (i.e. θ_r = 0°). Completely wetted areas < 2 cm^2. Together they cover < 90 % of the tested area.
5	Some completely wetted areas > 2 cm^2, which cover < 90 % of the tested area.
6	Wetted areas cover > 90 %, i.e. small unwetted areas (spots/ traces) are still observed.
7	Continuous water film over the whole tested area.

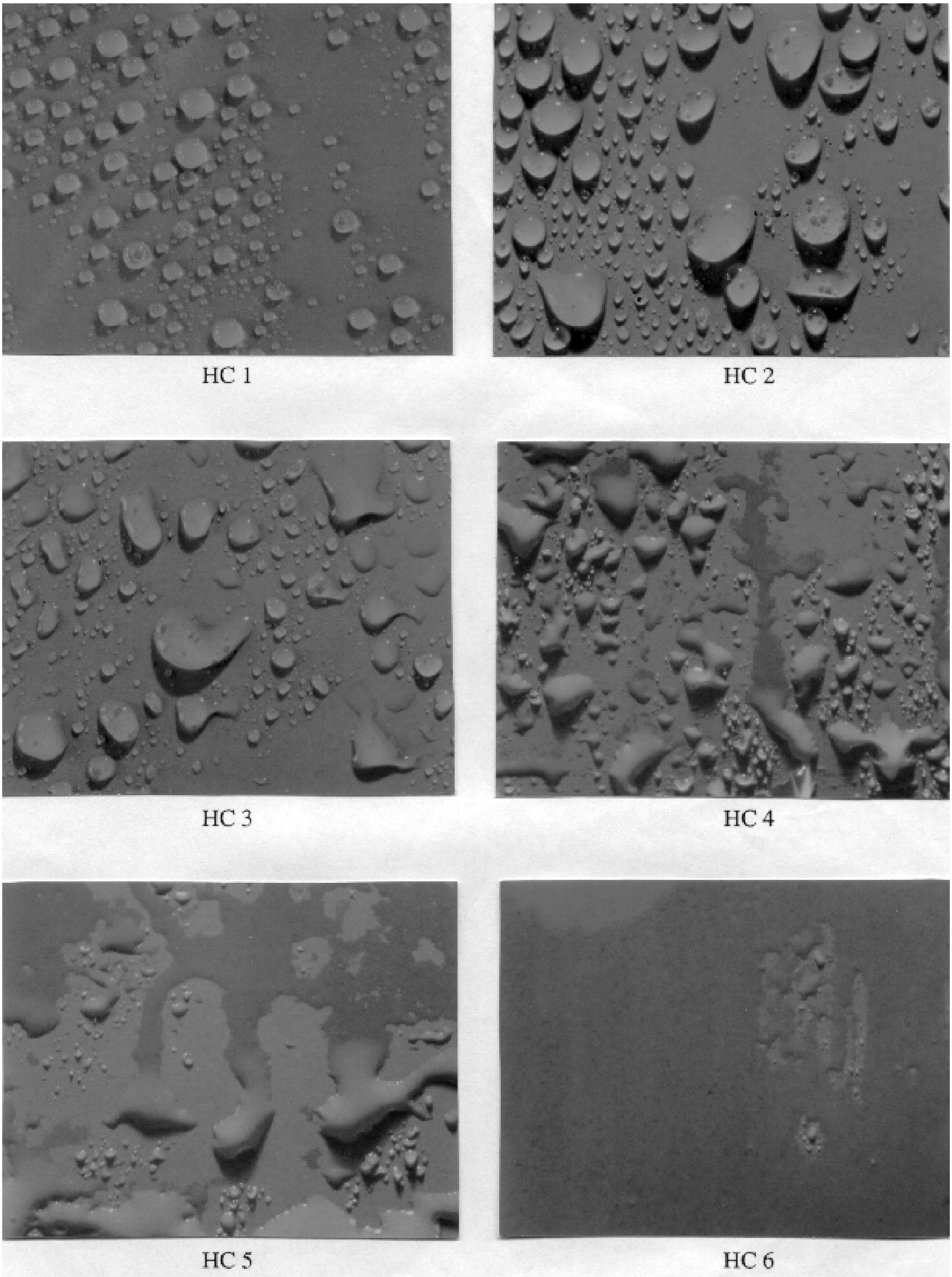


Fig. 10. Typical examples of surfaces with HC from 1 to 6 (natural size).

Test report:
The test report shall include the following information:

General information
Location, station, line
Date and time of the judgement
Weather conditions (temperature, wind, precipitation)
Performed by

Test object
Type of insulator
Identity (item no., position)
Voltage
Date of installation or application of coating (type of coating)
Mounting angle (vertical, horizontal, inclined x deg)

Hydrophobicity class
HC for different positions: along the insulator (shed no.), along the surface within each shed sequence (top, bottom, core, large shed, small shed, etc.)
Differences (if any) around the insulator circumference an easier recording during the examination.

2.6.2 Sample collection and status determination of silicone grease on porcelain insulators

WARNING

Make sure that the transformer is de-energized and out of service before any work is performed on the bushing.

This instruction describes the procedure for sample collection of silicone grease on insulators.

2.6.2.1 Test equipment

The following material is required at sampling of silicone:
- Three copper foils, dimension 15 x 70 x (0.2 - 0.3) mm.
- Screw-capped glass jar, size sufficient to embrace the foils.
- Disposable gloves.

Use the gloves when handling the sampling equipment.

2.6.2.2 Sample collection

Procedure

Use the disposable gloves and pick up a foil from the jar.
The grease sample shall be collected on the foil by scratching along the porcelain surface. This shall be performed in a way which leaves as little as possible of the grease layer on the insulator.
The total sample collection area should not be less than 15 cm^2 and the total amount of collected grease should not be less than 1 g (~1 cm^2).To meet these demands it may be necessary to use all three foils or more.
Place the foil(s) with the grease in the jar close the cap.
Measure the sample collection area.
Change gloves for next sample collection.
If possible, take photos of a typical sample collection area before and after the sample collection is carried out.

Sample marking

Each glass jar with grease sample should be marked with sample collection date, type of insulator and designation, sample collection position and sample collection area.
The sample mrking can also be performed by giving the glass jars individual numbers and the corresponding identification on a separate list.

The description of the position should be in the following order:

Position: top	corresponds to the position along the insulator.
12 o’clock	corresponds to the position along the insulator.
SW	corresponds to the point on the compass (for transducers)
upper	corresponds to the position on the shed

The positions for wall bushings are also illustrated in Fig. 11.

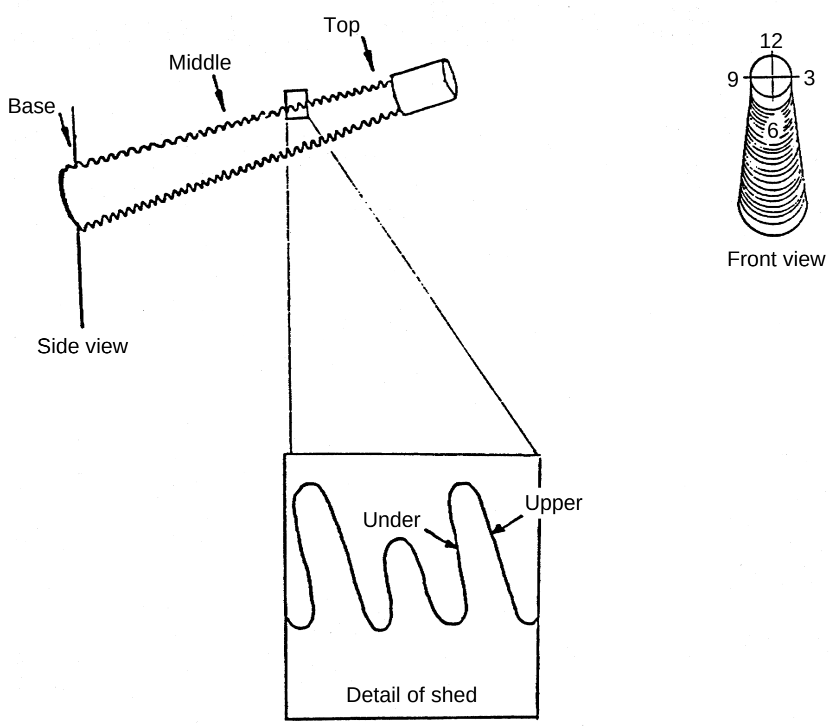


Fig.11. Sample collection positions on a wall bushing.

Packing
Place the glass jars in a steady way in a box with the caps upwards. Mark the box “This side up”.

Send the sample for analyse to ABB Components.

2.6.3 Instruction for thickness measurement of silicone grease on porcelain insulators.

WARNING

Make sure that the transformer is de-energized and out of service before any work is performed on the bushing.

This instruction describes the procedure for thickness measurements of silicone grease on insulators.

2.6.3.1 Test equipment

The equipment needed for measuring of thickness is one squared copper strip, dimensions 15 x 200 x 2 mm and one measuring cup with a volume of 5 ml. (Tea spoon with a well defined volume).

2.6.3.2 Measuring procedure

Use the 15 mm side of the copper stripe as a scraper. Collect the grease by scraping from the outer tip of the big shed to the inner valley in strict radial direction as described in Fig. 12 below.

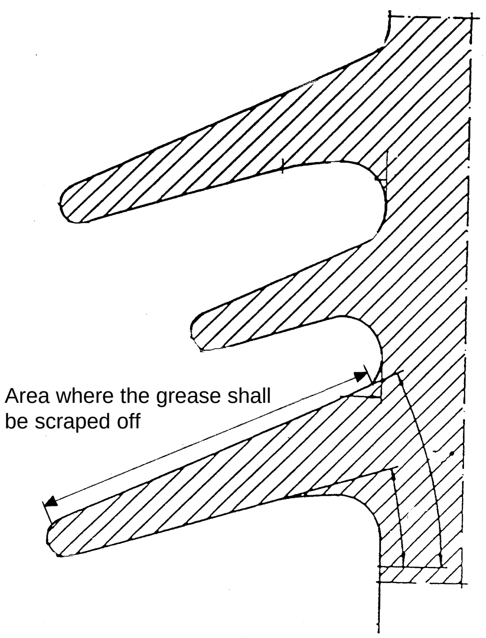


Fig. 12.

No grease shall be visible after the copper stripe scraper has passed the surface. Put the grease, which have been scraped off, in the measuring cup
Repeat the scraping procedure until the cup is full (5 ml).
The coating thickness is calculated by using the number of times the scraping procedure is performed.

In Table 5 the coating thickness is listed versus the number of scrapings. This table is valid only for short-long 95/95 profile which is used on ABB pole wall bushings at Radisson, Nicolet and Sandy Pond.

Table 5. Conversion no. of scrapping to coating thickness.

Number of scrapings	Coating thickness (mm)
3	1.1
4	0.85
5	0.68
6	0.57
7	0.49
8	0.42
9	0.38
11	0.31

For other shed profiles please contact ABB Components for advise.

2.7 Thermovision

By use of Ir-sensitive camera, see Fig. 13, hot spot on the bushing surface can be detected. At maximum rated current, the bushing outer terminal takes a temperature of about 35-45 °C above the ambient air. Significantly higher temeratures, especially at lower current loading, can be sign of bad connections.

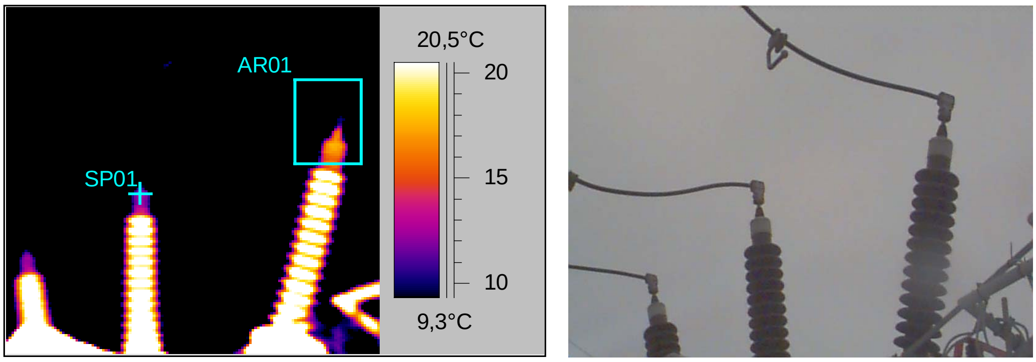


Fig.13. Measurement indicating poor current path between bushing inner and outer terminal.

2.8 De-polymerization analysis

De-polymerization analysis is a method of determining ageing of cellulose in OIP bushings. The method require that the bushing is taken apart and a paper sample is taken from the condenser body.

3 Conditioning

In general bushings delivered from ABB Components shall be considered maintenance- free. However inspection and service experience will in some cases lead to conditioning of bushings.

In the following chapters cleaning of insulators and silicone grease treatment are described. There are several other conditioning methods possible for bushings, such as painting, RTV coating, preparation with shed-extenders (booster sheds), etc, not covered in this document. For guidance please contact ABB Components.

3.1 Cleaning of insulators

WARNING

Make sure that the transformer is de-energized and out of service before any work is performed on the bushing.

CAUTION: *Avoid having solvent on the gasket and porcelain joints.*

Under conditions of extreme pollution it may be necessary to clean the insulator surface.

3.1.1 Porcelain insulators

Clean the porcelain insulator with water-jet or wiping with a moist cloth. If necessay, ethyl-alcohol or ethyl-acetatte may be used.

3.1.2 Silicon rubber insulators

Clean the porcelain insulator with water-jet or wiping with a moist cloth. If necessay, ethyl-alcohol or ethyl-acetatte may be used. 1,1,1, -Thrichlorethane or Methylchloride are not recommended due to their possibly harmful and environmentally detrimental properties.

3.2 Silicone grease treatment of wall bushings

The following method is primary developed for grease application on wall bushings in DC operation where uneven wetting may be problem for bushing operation. However, the treatment may also be useful at installations close to the sea where salted winds may cause external corona even if extreme arcing/creepage distances are specified.

WARNING

Make sure that the transformer is de-energized and out of service before any work is performed on the bushing.

Care should be taken to avoid contact with the skin, face and eyes.
Contamination of the eyes should be removed by irrigation with clean water.
Contamination of the skin should be removed by washing with soap and water.
If solvent is used use goggles protective gloves and if needed respiratory mask.
Precautions shall be taken in accordance with the manufacturer's recommendations.

When skylift is used, local safety recommendations shall be followed. Move the skylift carefully when working close to the insulators to avoid damage on the porcelains.
Finally care should be taken not leave traces of grease on floor, ladders, scaffoldings or supporting structures, as the grease makes them slippery and dangerous for personnel.

Silicone grease has a high flash point but will burn if involved in a fire. Normal extinguishing media may be used.

Regarding solvent used we refer to the recommendations of the manufacturer.

Silicone oil or grease could cause problems in low voltage contacts or relays when SiO_2 (with insulating properties) is produced in connection with arcing.

3.2.1 Purchase of silicone grease solvent

Approved quality: Wacker P4
Supplier: Wacker
The grease shall meet the requirements in the material specification 1173 7011-113, wich can be recieved on request from ABB Components.

Tests to be performed by the supplier:
Unworked penetration
Worked penetration
A certificate on the measured values shall be supplied together with each batch of grease.

3.2.2 Criteria for reapplication

The expected lifetime for a silicone grease coating according to this specification is 3 years or more. It is recommended to plan for reapplication of the grease every second year initially but extend the interval to three years or more as long as the grease fulfill the requirements below. The application shall be performed at the yearly maintenance stop. At the yearly stop between the year for application the status of the grease has to be judged.

This manual comprises two major methods for supervision and diagnosis of grease in service:

Judging of hydrophobicity
The check should be performed in accordance to the method described in chapter hydrophobicity classification.

Twelve test areas on each insulator shall be selected as follows:
Three positions along the bushing, top (energized end), middle and the base end of the insulator. At each position the hydrophobicity shall be checked on upper and under side of the larger shed for both upper (12 o'clock) and under (6 o'clock) side of the bushing.

If the hydrophobicity is of class 4 or higher, a control of the hydrophobicity shall also be performed on the adjacent shed. This provides a judgement if the reduction in hydrophobicity is local or extends over the whole insulator.

Photo documentation of some representative surfaces during the test is desirable and should always be performed for surfaces with the classification 4 or higher.

Renewal of silicone grease is recommended as soon as possible, if the surface of class 6 or 7 exceeds 50 % of the total creepage length of the insulator.

Visual inspection
The visual inspection shall take into consideration changes in form of cracks, blisters, peeling, sliding and erosion.

The inspection should be performed on all silicone greased insulators once a year. The inspections should be recorded on a form. If any changes are observed, photo documentation is desirable.

Additional requirements for recoating interval longer than two years
The insulator shall after two years in service have a surface of less than class 4 of 50 % of total creepage length of the insulator and less than class 5 of 25 % of the total creepage length of the insulator. Not more than one of twelve isolated test areas from the test described above are of class of 6 or 7.

Removability
Remove the grease on a half turn on one shed sequence by using the scraper 9779 023-A.The time needed to do this, and fulfil the criteria in item "Pretreatment before reapplication", shall not be more than 30 s.

Electrical activity
The bushing shall be observed by a pair of binoculars during rain and fog conditions regarding partial discharges. No activity shall be permitted.

Chemical analysis
Sample collection of silicone grease should be performed according to chapter Sample collection and status determination of silicone grease on insulators above.

One bushing is selected in each station.
Three samples shall be taken. Two of the samples shall be taken in the area where the highest hydrophobicity class is measured. The third sample shall be taken in the area where the lowest hydrophobicity class is measured.

The samples may be sent to ABB Components for analysis regarding molecular weight distributions, contamination and silicone oil content. Changes in the chemical composition will provide further information of the aging status of the grease.

3.2.3 Precautions at application and reapplication

Pretreatment before the first application
Before the silicone grease is applied the first time the porcelain surface must be thoroughly cleaned by rinsing with plenty of water followed by hand wiping of the insulator with alcaline detergent solution and finally rinsing the insulator with plenty of water. If the insulator is light polluted, cleaning with just water and rags are sufficient.

Pretreamtment before reapplication
Before the applications of a new layer of grease can start, the old layer shall be removed. The removal is made by means of specially shaped hand held scrapers (Provided by ABB, No 9779 023-A). Most of the visibly polluted grease shall be removed. At least 90% of the insulator surface shall be touched by the scrapers. Traces of old grease left on the surface is accepted as it even helps to ensure an intimate contact between the new layer and the insulator surface.

If hand wiping is used, the following solvents are recommended in order to soften the polluted layer: Isopropanol and Xylene.

3.2.4 Application

Ambient conditions
As the insulator surface has to be dry at the application of grease, either the application must be done at dry weather or a rain protection has to be put up. For practical reasons application shall not be performed at a temperature below -10 °C or at a wind speed higher than 10 meter/second.

Thickness
The target for the average thickness is 0.3-0.9 mm. The function of the grease is not in any way sensitive to uneveness in the coating. Bare spots on the insulators will after a certain time in service be coated by self spreading silicone oils coming from more grease rich areas.

Isolated areas with grease thickness up to 4 mm are permitted as well as isolated areas with coating thickness below 0.05 mm. The area of each such surface shall be limited to 100 cm^2.

The thickness of the coating shall be controlled according to chapter Instruction for thickness measurement of silicone grease on insulators.

Procedure
Apply the grease by hand using a painter's glove.

To minimize the time for application it is recommended to use two skylifts with two workers in each skylift.

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