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Nuclear power plants – Instrumentation and control important to safety – Electrical equipment condition monitoring methods – Part 2: Indenter ~~modulus~~ measurements

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colour inside

Nuclear power plants – Instrumentation and control important to safety – Electrical equipment condition monitoring methods – Part 2: Indenter ~~modulus~~ measurements

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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FOREWORD

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This redline version of the official IEC Standard allows the user to identify the changes made to the previous edition IEC/IEEE 62582-2:2011+AMD1:2016 CSV. A vertical bar appears in the margin wherever a change has been made. Additions are in green text, deletions are in strikethrough red text.

IEC/IEEE 62582-2 was prepared by subcommittee 45A: Instrumentation, control and electrical power systems of nuclear facilities, of IEC technical committee 45: Nuclear instrumentation, in cooperation with Nuclear Power Engineering Committee of the IEEE, under the IEC/IEEE Dual Logo Agreement between IEC and IEEE. It is an International Standard.

This document is published as an IEC/IEEE Dual Logo standard.

This second edition cancels and replaces the first edition published in 2011, and its Amendment 1:2016. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) Modification of the title;

b) Consideration of publication of IEC/IEEE 60780-323.

The text of this International Standard is based on the following IEC documents:

FDIS	Report on voting
45A/1434/FDIS	45A/1444/RVD

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this International Standard is English.

This document was drafted in accordance with the rules given in the ISO/IEC Directives, Part 2, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

A list of all parts of IEC/IEEE 62582 series, under the general title *Nuclear power plants – Instrumentation and control important to safety – Electrical equipment condition monitoring methods*, can be found on the IEC website.

The IEC Technical Committee and IEEE Technical Committee have decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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INTRODUCTION

a) Technical background, main issues and organisation of this standard

This part of IEC/IEEE 62582 specifically focuses on indenter modulus methods for condition monitoring for the management of ageing of electrical equipment installed in nuclear power plants. The indenter method is commonly used to carry out measurements on cables (jackets, insulation) and O-rings.

This part 2 of IEC/IEEE 62582 contains detailed descriptions of condition monitoring based on indenter modulus measurements.

The IEC/IEEE 62582 series is issued with a joint logo which makes it applicable to the management of ageing of electrical equipment qualified to IEEE as well as IEC Standards.

~~Historically, IEEE Std 323-2003 introduced~~ IEC/IEEE 60780-323 includes the concept and role that condition based qualification could be used in equipment qualification as an adjunct to qualified life. In equipment qualification, the condition of the equipment for which acceptable performance was demonstrated is the qualified condition. The qualified condition is the condition of equipment, prior to the start of a design basis event, for which the equipment was demonstrated to meet the design requirements for the specified service conditions.

Significant research has been performed on condition monitoring techniques and the use of these techniques in equipment qualification as noted in NUREG/CR-6704, Vol. 2 (BNL-NUREG-52610) and JNES-SS-0903, 2009 and IAEA-TECDOC-1825:2017.

It is intended that this IEC/IEEE document be used by test laboratories, operators of nuclear power plants, systems evaluators, and licensors.

b) Situation of the current standard in the structure of the IEC SC 45A standard series

IEC/IEEE 62582-2 is the third level IEC SC 45A document tackling the specific issue of application and performance of indenter modulus measurements in management of ageing of electrical instrument and control equipment in nuclear power plants.

IEC/IEEE 62582-2 is to be read in association with IEC/IEEE 62582-1, which provides background and guidelines for the application of methods for condition monitoring of electrical equipment important to safety of nuclear power plants.

For more details on the structure of the IEC SC 45A standard series, see item d) of this introduction.

c) Recommendations and limitations regarding the application of this standard

It is important to note that this document establishes no additional functional requirements for safety systems.

d) Description of the structure of the IEC SC 45A standard series and relationships with other IEC documents and other bodies documents (IAEA, ISO)

~~The top-level document of the IEC SC 45A standard series is IEC 61513. It provides general requirements for I&C systems and equipment that are used to perform functions important to safety in NPPs. IEC 61513 structures the IEC SC 45A standard series.~~

~~IEC 61513 refers directly to other IEC SC 45A standards for general topics related to categorisation of functions and classification of systems, qualification, separation of systems, defence against common cause failure, software aspects of computer-based systems, hardware~~

~~aspects of computer-based systems, and control room design. The standards referenced directly at this second level should be considered together with IEC 61513 as a consistent document set.~~

~~At a third level, IEC SC 45A standards not directly referenced by IEC 61513 are standards related to specific equipment, technical methods, or specific activities. Usually these documents, which make reference to second-level documents for general topics, can be used on their own.~~

~~A fourth level extending the IEC SC 45A standard series, corresponds to the Technical Reports which are not normative.~~

~~IEC 61513 has adopted a presentation format similar to the basic safety publication IEC 61508 with an overall safety life-cycle framework and a system life-cycle framework and provides an interpretation of the general requirements of IEC 61508-1, IEC 61508-2 and IEC 61508-4, for the nuclear application sector. Compliance with IEC 61513 will facilitate consistency with the requirements of IEC 61508 as they have been interpreted for the nuclear industry. In this framework IEC 60880 and IEC 62138 correspond to IEC 61508-3 for the nuclear application sector.~~

~~IEC 61513 refers to ISO as well as to IAEA 50-C-QA (now replaced by IAEA GS-R-3) for topics related to quality assurance (QA).~~

~~The IEC SC 45A standards series consistently implements and details the principles and basic safety aspects provided in the IAEA code on the safety of NPPs and in the IAEA safety series, in particular the Requirements NS-R-1, establishing safety requirements related to the design of Nuclear Power Plants, and the Safety Guide NS-G-1.3 dealing with instrumentation and control systems important to safety in Nuclear Power Plants. The terminology and definitions used by SC 45A standards are consistent with those used by the IAEA.~~

The IEC SC 45A standard series comprises a hierarchy of four levels. The top-level documents of the IEC SC 45A standard series are IEC 61513 and IEC 63046.

IEC 61513 provides general requirements for instrumentation and control (I&C) systems and equipment that are used to perform functions important to safety in nuclear power plants (NPPs). IEC 63046 provides general requirements for electrical power systems of NPPs; it covers power supply systems including the supply systems of the I&C systems.

IEC 61513 and IEC 63046 are to be considered in conjunction and at the same level. IEC 61513 and IEC 63046 structure the IEC SC 45A standard series and shape a complete framework establishing general requirements for instrumentation, control and electrical power systems for nuclear power plants.

IEC 61513 and IEC 63046 refer directly to other IEC SC 45A standards for general requirements for specific topics, such as categorization of functions and classification of systems, qualification, separation, defence against common cause failure, control room design, electromagnetic compatibility, human factors engineering, cybersecurity, software and hardware aspects for programmable digital systems, coordination of safety and security requirements and management of ageing. The standards referenced directly at this second level should be considered together with IEC 61513 and IEC 63046 as a consistent document set.

At a third level, IEC SC 45A standards not directly referenced by IEC 61513 or by IEC 63046 are standards related to specific requirements for specific equipment, technical methods, or activities. Usually these documents, which make reference to second-level documents for general requirements, can be used on their own.

A fourth level extending the IEC SC 45 standard series, corresponds to the Technical Reports which are not normative.

The IEC SC 45A standards series consistently implements and details the safety and security principles and basic aspects provided in the relevant IAEA safety standards and in the relevant documents of the IAEA nuclear security series (NSS). In particular this includes the IAEA requirements SSR-2/1 , establishing safety requirements related to the design of nuclear power plants (NPPs), the IAEA safety guide SSG-30 dealing with the safety classification of structures, systems and components in NPPs, the IAEA safety guide SSG-39 dealing with the design of instrumentation and control systems for NPPs, the IAEA safety guide SSG-34 dealing with the design of electrical power systems for NPPs, the IAEA safety guide SSG-51 dealing with human factors engineering in the design of NPPs and the implementing guide NSS17 for computer security at nuclear facilities. The safety and security terminology and definitions used by the SC 45A standards are consistent with those used by the IAEA.

IEC 61513 and IEC 63046 have adopted a presentation format similar to the basic safety publication IEC 61508 with an overall life-cycle framework and a system life-cycle framework. Regarding nuclear safety, IEC 61513 and IEC 63046 provide the interpretation of the general requirements of IEC 61508-1, IEC 61508-2 and IEC 61508-4, for the nuclear application sector. In this framework, IEC 60880, IEC 62138 and IEC 62566 correspond to IEC 61508-3 for the nuclear application sector.

IEC 61513 and IEC 63046 refer to ISO 9001 as well as to IAEA GSR part 2 and IAEA GS-G-3.1 and IAEA GS-G-3.5 for topics related to quality assurance (QA).

At level 2, regarding nuclear security, IEC 62645 is the entry document for the IEC/SC 45A security standards. It builds upon the valid high level principles and main concepts of the generic security standards, in particular ISO/IEC 27001 and ISO/IEC 27002; it adapts them and completes them to fit the nuclear context and coordinates with the IEC 62443 series. At level 2, IEC 60964 is the entry document for the IEC/SC 45A control rooms standards, IEC 63351 is the entry document for the human factors engineering standards and IEC 62342 is the entry document for the ageing management standards.

NOTE 1 It is assumed that for the design of I&C systems in NPPs that implement conventional safety functions (e.g. to address worker safety, asset protection, chemical hazards, process energy hazards) international or national standards would be applied.

NOTE 2 IEC TR 64000 provides a more comprehensive description of the overall structure of the IEC SC 45A standards series and of its relationship with other standards bodies and standards.

NUCLEAR POWER PLANTS – INSTRUMENTATION AND CONTROL IMPORTANT TO SAFETY – ELECTRICAL EQUIPMENT CONDITION MONITORING METHODS –

Part 2: Indenter ~~modulus~~ measurements

1 Scope ~~and object~~

This part of IEC/IEEE 62582 contains methods for condition monitoring of organic and polymeric materials in instrumentation and control systems using the indenter ~~modulus~~ measurement technique in the detail necessary to produce accurate and reproducible measurements. It includes the requirements for the selection of samples, the measurement system and measurement conditions, and the reporting of the measurement results.

The different parts of IEC/IEEE 62582 are measurement standards, primarily for use in the management of ageing in initial qualification and after installation. IEC/IEEE 62582-1 includes requirements for the application of the other parts of the IEC/IEEE 62582 series and some elements which are common to all methods. Information on the role of condition monitoring in the qualification of equipment important to safety is found in ~~IEEE Std 323~~ IEC/IEEE 60780-323.

This document is intended for application to non-energised equipment.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO, IEC and IEEE maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp
- IEEE Standards Dictionary Online: available at http://dictionary.ieee.org

3.1
indenter modulus
ratio between the changes in applied force and corresponding displacement of a probe of a standardised shape, driven into a material

Note 1 to entry: It is expressed in N·mm^{-1}.

Note 2 to entry: The term “modulus” typically refers to the modulus of elasticity of a material which is defined as the ratio of the applied stress and the corresponding strain and is expressed in N·m^{-2} (Pa). However, in the use of the indenter, it has become common practice to use the term indenter modulus to describe the ratio of the change in applied force to material deformation and express it in N·mm^{-1}.

4 Abbreviated terms and acronyms

DBE	design basis event
IM	indenter modulus
SiR	silicone rubber
CSPE	chlorosulphonated polyethylene
EPDM	ethylene propylene diene monomer
XLPE	crosslinked polyethylene

5 General description

A typical indenter uses an instrumented probe, which is driven at a fixed velocity into the material and includes a load cell or similar force-measuring device, connected to the probe, which measures the force necessary to maintain the constant velocity. The probe's displacement is measured by an appropriate transducer. The travel and force are purposely limited to protect the material from permanent damage. The indenter modulus is calculated by dividing the change in force by the corresponding displacement during inward travel.

6 Applicability, reproducibility and complexity

6.1 General

When organic and polymeric materials age, they often harden which will result in an increase of indenter modulus. Some materials, such as some formulations of butyl rubber, soften during thermal and/or radiation ageing. The purpose of monitoring changes in indenter modulus is to estimate degradation rates and levels induced by ageing.

6.2 Applicability

The indenter method is commonly used to carry out measurements on cables (jackets, insulation) and O-rings. Its use requires special fixtures depending on the geometry of the samples.

This method should only be applied to materials whose hardness changes monotonically with ageing.

The indenter method ~~may~~ can be carried out on equipment with high integrity in a non-invasive manner. However, the process of performing indenter measurements on equipment in field should include controls to ensure that damage – from the probe or from handling in order to access suitable measurement points – has not been imparted to the equipment. The process should include correction of any equipment that has been damaged or suspected of incurring damage.

Measurements in the field require access to the exterior wall of the equipment. For field measurements on cables, this often limits the measurements to jacket materials. It ~~may~~ can be possible to assess the condition of cable insulation from indenter measurements on its jacket if there is a known relationship between the ageing degradation of the jacket material and the degradation of the insulation. This relationship shall be justified to be valid and sufficiently sensitive to provide the valid monitoring through the life of the test object.

6.3 Reproducibility

Indenter modulus values can be influenced by variability in specimen dimensions and construction, temperature and moisture content of the specimen, stabilisation of the specimen, and contamination of the specimen. If measurements are made under excessive vibration, this can influence the measured value. The influence by variability in the specimen dimensions and construction is typically the case for measurements on cables, where the measurement point may be situated above a cavity beneath the jacket surface. The cross-section of typical cable core insulation ~~may~~ can differ substantially from that of an ideal tube and can result in variability in the measured values of indenter modulus depending on where the measurement is made. These variations tend to be localised. Measurements shall be taken at several points on the equipment to compensate for these local variations (see 7.6).

An illustration of variations due to variability in specimen dimensions and construction is given in Annex A.

~~NOTE~~ A good knowledge of the construction of the equipment is important before the selection of measurement positions is made. In the case of loosely constructed cables, the variability is expected to be high and it is important that the measurements on the jacket are made over a conductor rather than free space.

6.4 Complexity

The degree of complexity experienced during indenter modulus measurements in the field will often depend on cable accessibility. Existing instruments ~~may~~ can be used in the field on cables that are accessible. In this case, data generation is rapid and measurements at a large number of points can be carried out over short time periods. Instruments can be configured such that data are generated and stored directly. Measurements on equipment with more complex geometries and limited accessibility ~~may~~ can require the development of special fixtures. The same fixture shall be used for repeated indenter modulus measurements.

7 Measurement procedure

7.1 Stabilisation of the polymeric materials

An appropriate time period shall be allowed for the polymeric materials in recently manufactured equipment to stabilise before any condition monitoring or accelerated ageing programmes are carried out. The time period over which the polymeric materials stabilise is normally dependent on the processing additives and polymer composition. If manufacturers' stabilisation time data are not available, a period of 6 months should be allowed.

7.2 Sampling and measurement locations

Laboratory measurements of indenter modulus on samples selected from the field and indenter modulus measurements in the field only provide information on the status of the equipment at a specific location. Knowledge of the environmental conditions in representative areas during plant operation is a prerequisite for selecting locations. Since ~~equipment~~ heating and radiation effects on equipment under test could be most apparent closest to the sources of heat and radiation, the choice of locations should consider capturing the potential for significant ageing effects near sources of heating and radiation. The position of the test locations and available information about the environmental time history of the locations selected shall be documented.

Sampling and measurement procedures shall comply with local instructions, taking into account the safety of personnel and equipment. Handling of equipment during measurement or removal of samples from the plant should be minimised, e.g. cables should not be bent more than necessary for the measurement or for the removal of the sample.

7.3 Conditions for measurement

The surface on which the measurements are made shall be cleaned of surface debris. In the field, it ~~may~~ can be necessary to apply a dry wipe to remove accumulated dirt from the surface and prevent contamination of the indenter instrument. Under no circumstances shall solvents be used for surface cleaning.

The indenter modulus varies with the temperature and moisture content of the sample as shown in Annex A.

When measurements are carried out in the laboratory, e.g. after accelerated thermal ageing, they shall be made in a surrounding air temperature of (20 ± 5) °C and a relative humidity of 45 % to 75 %. Samples shall be allowed time to reach equilibrium with their surroundings before measurements are started.

NOTE ~~1~~ Where the materials are hygroscopic, it ~~should be~~ is noted that the sample can be extremely dry after artificial accelerated ageing as a consequence of long-term exposure to high temperatures in an oven. For these materials, the values of indenter modulus measured can be significantly higher than for a sample in equilibrium with the laboratory atmosphere. This is particularly important for condition monitoring of hygroscopic insulation material when the final value of indenter modulus, on which qualified condition is based, is measured on completion of accelerated thermal ageing before the sample is subjected to a DBE test. Clause A.3 provides guidance on dealing with this specific concern.

It may not be possible to make field measurements in standard atmospheric conditions. In such cases the surrounding air temperature and the temperature at the surface at which the measurements are made shall be recorded.

~~NOTE 2~~ Annex A shows a method for transformation of a measured indenter modulus to a corresponding modulus at a different temperature. In addition to reporting the temperature at which the value has been measured, it is recommended that the corresponding value at 20 °C be calculated and reported.

7.4 Instrumentation

The indenter functions by driving an instrumented probe at a fixed velocity into the material whilst a load cell or similar force-measuring device, connected to the probe, measures the applied force. The probe shall have the shape of a truncated steel cone with the geometry and dimensions shown in Figure 1. The probe's displacement is measured by an appropriate transducer. The point at which the tip of the probe is brought into contact with the material is sensed by a change in force. The probe's total displacement is normally limited to a fraction of a mm to prevent permanent deformation and to keep within the range of approximate linear proportionality between force and displacement. The indenter modulus (IM) is then calculated by dividing the change in force by the corresponding displacement during inward travel. The small displacements and loads that occur during this process prevent permanent effects on the material.

NOTE 1 Although the total displacement is limited, for some materials the relationship between force and displacement is still significantly non-linear.

Dimensions in millimetres

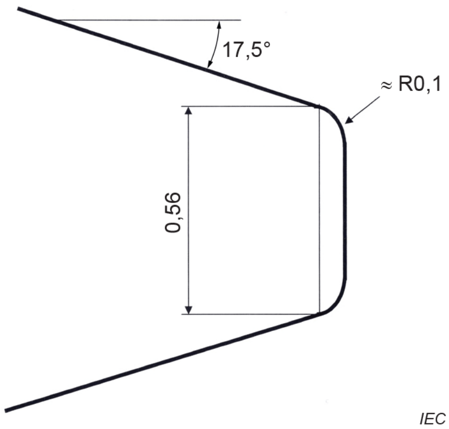


Figure 1 – Geometry and dimensions of the profile of the probe tip (truncated cone) used in the indenter

A typical indenter is a hand held ~~cylindrical~~ instrument. At the head of the instrument, an appropriate clamping device holds a cable or wire securely in position so that the probe can be driven uniformly into the jacket or insulation of the cable or wire respectively. The probe is situated within the instrument and is attached to a sensitive load cell. A servo-controlled electric motor with appropriate gearing provides the capability to drive the probe towards the sample and the probe's position is measured by a transducer. A temperature sensor ~~is~~ can be located close to the clamping device. The power and servo-control to the electric motor, and outputs from the load cell, transducer and temperature sensor are fed by cable into a separate controller which ~~may~~ can be directly connected to a computer or capable of data storage in-situ which ~~may~~ can be downloaded into a remote computer. Parameters such as probe velocity, and maximum load, and displacement are preloaded into the controller before the start of measurement. The instrument is also designed such that the cable clamp can be modified to allow calibration of the load cell using an appropriate weight and the probe travel using a dial gauge.

NOTE 2 When measuring on a wire with small diameters the result could be more non-linear in the beginning of the curve due to that only a part of the tip of the anvil have contact with the sample. This could influence the reproducibility with only small changes in the way to perform the measurement. See Figure 2.

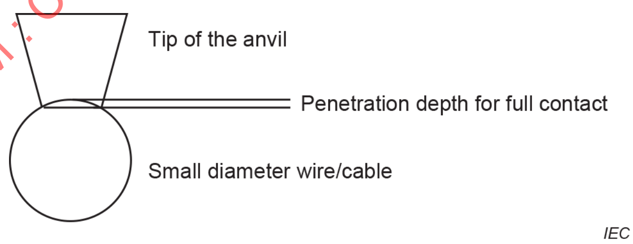


Figure 2 – Penetration depth for full contact on the tip of the anvil

7.5 Calibration and tolerances

The indenter and the measurement system shall be calibrated before each series of measurements in accordance with the manufacturer's instructions. The calibration shall be carried out on both the force sensor and probe velocity. The total error of force measurement shall be less than 3 % of the upper limit of the force range, including instrumentation tolerances as well as reading precision. The probe velocity shall be constant. The total measurement error of the required velocity shall be less than 2 %.

The user of the instrument shall have a defined process for visual inspection and measuring of the tip of the anvil. If wear or other damage to the tip of the anvil occurs to the extent that the dimensions are no longer according to Figure 1, then the anvil shall be replaced.

7.6 Selection of measurement points

In each of the selected locations for field measurements, measurements shall be carried out at several points and the mean value and standard deviation shall be reported. If the number of points is more than 7, the highest and lowest value shall be deleted before calculation of the mean value and the standard deviation. For measurements on cables, a minimum of three points around the circumference at each of three longitudinal positions shall be used. Where space is limited, it may not be possible to rotate around the cable circumference. In this case, a minimum of nine points shall be selected with a separation of 60 mm to 100 mm along the cable length.

If the measurement curve is not smooth maybe because of slipping due to low clamping force, the measurement value can be excluded and a new measurement be performed.

In the case of laboratory measurements on samples of cables, a minimum of three points around the circumference at each of three longitudinal positions shall be used. None of the measurement points shall be less than 100 mm from the ends of the sample.

For measurements on O-rings, a similar number of points shall be measured if the size of the O-ring allows.

7.7 Selection of probe velocity and maximum force

Before the start of the measurement, the test parameters shall be loaded into the measurement system. In particular, the required maximum load and maximum displacement should be set as limits to prevent damage to the equipment measured.

The probe velocity can have a significant influence on the measured value of indenter modulus. The probe velocity shall be 5 mm·min^{-1} to 5,2 mm·min^{-1}. The probe velocity that is selected shall be reported.

The maximum force that is selected needs to be a compromise between a value which is high enough to achieve reasonable resolution in the displacement axis and a value that is low enough to ensure that the probe does not damage the cable. For many polymeric insulation materials, a maximum force of 10 N is recommended. This will normally result in a probe penetration depth which is significantly less than 1 mm. For certain insulation materials, such as SiR, a maximum value lower than 10 N ~~may~~ can be required to avoid excessive penetration.

NOTE Some measurement systems contain independent mechanisms to protect the equipment under test by limiting the probe force and travel distance.

7.8 Clamping

When carrying out measurements on cables, the measured value of indenter modulus ~~may~~ can be strongly affected by variations in the force used to keep the cables securely in position within the clamp. In order to minimise these effects, the cable shall be clamped using the minimum force required to keep it in place. It is important that a consistent clamping methodology is used. Problems in clamping shall be included in the measurement report.

7.9 Determination of the value of the indenter modulus

The indenter modulus is determined by the slope of the force-displacement curve, and is expressed in N·mm^{-1}.

$$IM = (F_2 - F_1)/(d_2 - d_1) \tag{1}$$

where

IM is the indenter modulus;

F_i is the corresponding force value at displacement d_i.

IM shall be determined by using the values F_1 = 1 N and F_2 = 4 N, see Figure 3.

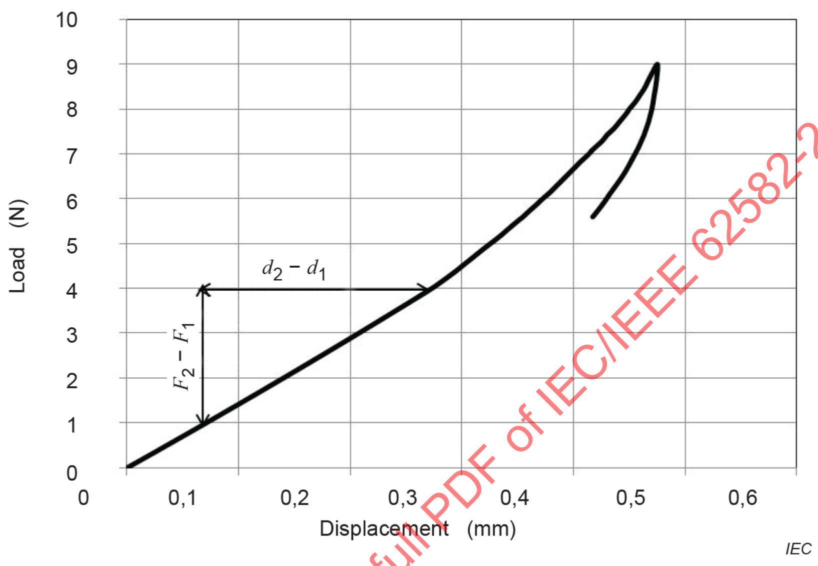


Figure 3 – Calculation of indenter modulus

NOTE Some instruments used for indenter measurements show the result in load versus time (in N·s^{-1}). The value of the indenter modulus in N·mm^{-1} is then calculated as the value in N·s^{-1} divided by the probe velocity in mm·s^{-1}.

7.10 Reporting

The measurement report shall as a minimum include the following items:

a) Identification of the equipment measured, including the material formulation. For selection of samples from the field or measurements in the field this shall include plant and location relative to heat and radiation sources (7.2).

b) Prehistory of the equipment. This ~~may~~ can include:

- indenter measurements on samples of new (un-aged) equipment: storage and time interval between production of the equipment sampled and start of the measurement (7.1);
- indenter measurements on artificially aged samples: ageing conditions of the samples (7.3);
- indenter measurements on naturally aged samples (e.g. field measurements): history of environmental conditions to which the sample has been subjected (7.2).

c) Place and date of the measurement (laboratory, on-site).

d) For laboratory measurement of samples subjected to artificial thermal ageing: time interval between removing the sample from the heat chamber until start of measurement (7.3).

e) Ambient and surface temperature at the time of measurement (7.3).

f) Other local conditions and situations encountered during measurement that ~~may~~ can influence the results.

g) Measurement instrumentation, including software version (7.4).

h) Calibration procedure (7.5).

i) Measurement points (7.6).

j) Probe velocity (7.7).

k) Maximum force (7.7).

l) Mounting of the sample and problems in clamping (7.8).

m) For measurements in the field: observations on the condition of the equipment before and after indenter measurements (7.2). Also deviation from the demands in this document, due to limited space, for example.

n) Mean value and standard deviation of indenter modulus (after deleting the highest and lowest value), in N·mm^{-1} together with information on the force interval for which it has been determined (normally 1 N to 4 N) (7.6 and 7.9).

  ~~NOTE~~ If the indenter measurements are made at a temperature above 25 °C, it is recommended that the value referenced to 20 °C is also reported, calculated according to Annex A.

o) Diagram showing a typical force versus displacement curve.

p) Any other information of importance in interpretation of the measurement results in relation to the purposes of the measurements.

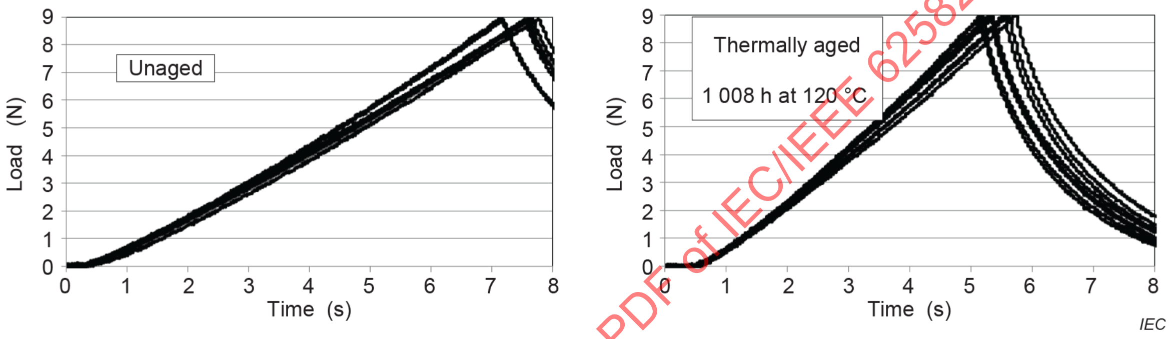
An example of a measurement report is given in Annex B.

Annex A
(informative)

Examples illustrating factors affecting the variation of the indenter modulus value

A.1 Example of influence of variability in equipment dimensions and construction

Figure A.1 illustrates the variations due to variability in equipment dimensions and construction, showing sets of data from indenter measurements at eight points on the jacket of a 7 core cable with jacket material CSPE and insulator material EPDM. The mean values and standard deviations of the indenter modulus measured were 15,57 N·mm^{-1} and 0,58 N·mm^{-1} for the unaged cable jacket, 23,21 N·mm^{-1} and 1,06 N·mm^{-1} for the thermally aged cable jacket.



NOTE The probe velocity was 5,2 mm·min^{-1} and the indenter modulus values were calculated from the slope between 1 N and 4 N by division by 5,2·60^{-1}.

Figure A.1 – Example of local variation of indenter modulus due to variation in equipment dimensions and construction

A.2 Examples of temperature dependence

These examples come from a study of the temperature dependence of the indenter values of three types of thermally aged cables:

– jacket and lead insulation materials CSPE,
– jacket material CSPE, lead insulation material XLPE,
– jacket and lead insulation materials EPDM.

The measurements were made at 9 (3×3) points on the jacket and the indenter modulus values were obtained from the slope of the force-distance curve between 1 N and 4 N. All cables had been thermally aged at 120 °C for 48 days. The measurements were made after temperature stabilisation at 21 °C, 35 °C and 50 °C.

Figure A.2 shows the results in terms of mean values and standard deviation of the indenter modulus.

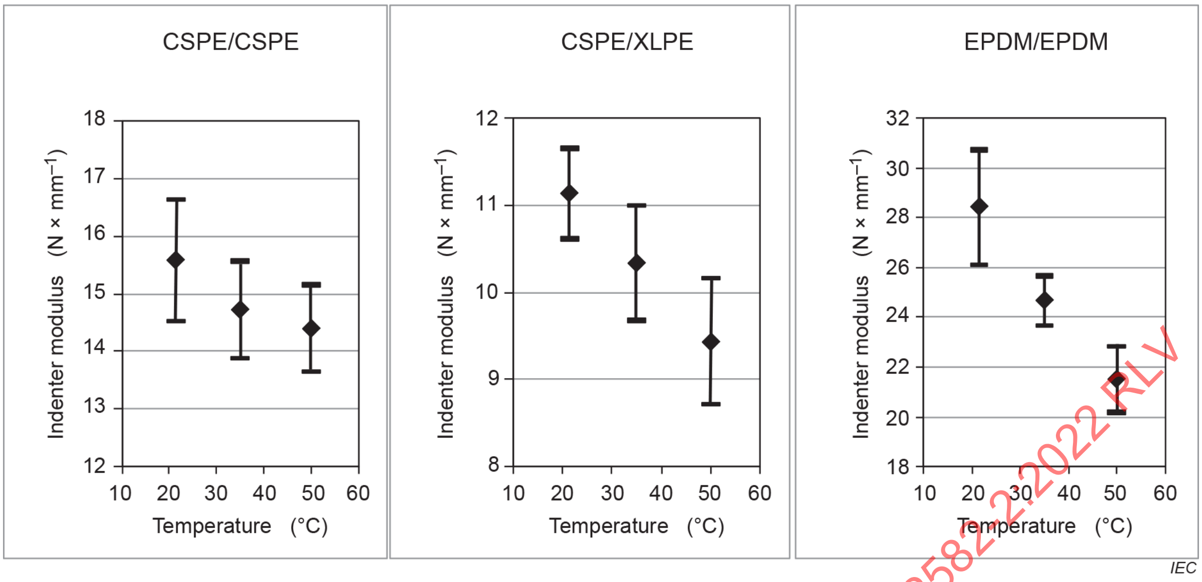


Figure A.2 – Indenter values measured at different temperatures

The results illustrate the temperature dependence of indenter modulus measurements.

In the case where indenter measurements are made at temperatures which differ substantially from the standard temperature for testing t_{ref} (20 °C), e.g. on site, normalisation to a value IM_{ref} at 20 °C can be made. The calculated value of IM_{ref} is given by the following empirical formula:

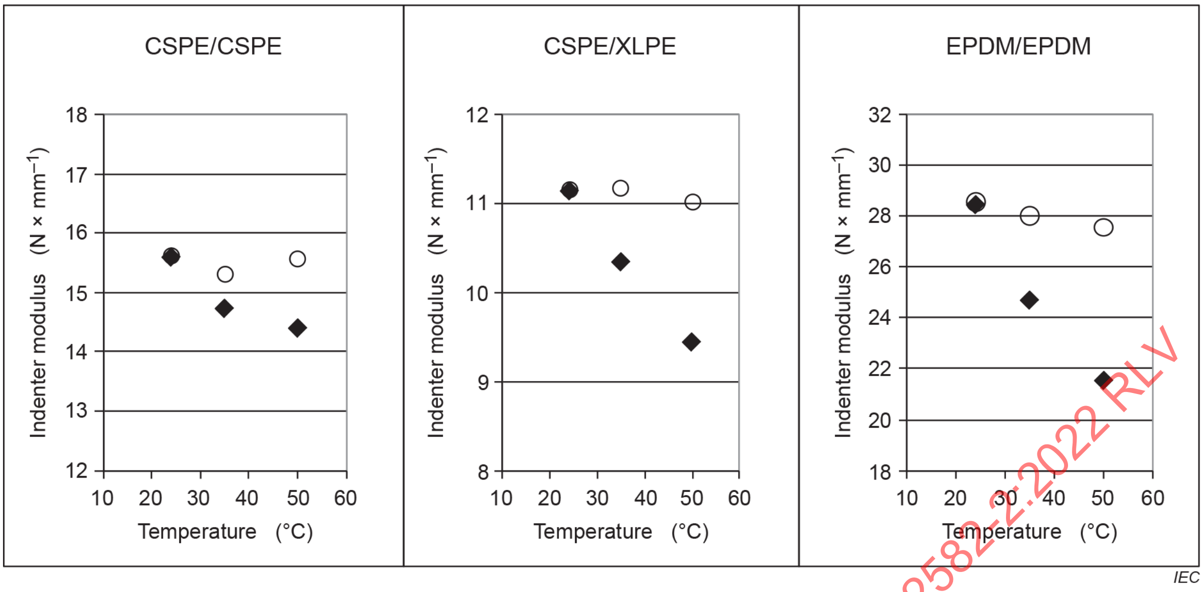
$$IM_{ref} = [1 + A \times (t - t_{ref}) / (t_1 - t_2)] \times IM_t$$

$$A = (IM_2 - IM_1) / [(IM_2 + IM_1)/2] \qquad \text{(A.1)}$$

where

t	is the temperature at which the measurement in the field is made;
IM_t	is the measured value of indenter modulus at temperature t;
IM_1 and IM_2	are the values of indenter modulus at two different temperatures t_1 and t_2 respectively from laboratory measurements made on the same material.

t_1 should be selected in the region of the highest temperature at which measurements in the field ~~may~~ can be made, and t_2 should be in the region of 20 °C. Figure A.3 shows the mean values in Figure A.2 normalised according to formula (A.1).



Key

Diamonds represent the measured value.

Circles represent the normalised value.

Figure A.3 – Normalised indenter mean values

The normalisation works well over the measurement temperature interval 20 °C to 50 °C.

To summarise, the recommendation is:

- If practicable, to measure the indenter modulus after stabilisation to a standard laboratory temperature of 20 °C.
- If it is foreseen that measurements will be made on site at significantly higher temperature than standard laboratory temperature, e.g. for comparison with qualified condition, it is recommended that the relevant value of A is determined and reported by using measurements at two temperatures (laboratory temperature and one elevated temperature, close to what can be expected in site measurements). This should be carried out after the artificial laboratory ageing which forms part of the initial qualification testing.

A.3 Examples of effects on the indenter modulus from drying out after high temperature ageing

Most organic and polymeric materials currently used in-containment are not significantly hygroscopic. If hygroscopic materials are used, the influence of the moisture content of the material on indenter modulus can be significant and should be taken into account. An example of the influence for such a material is shown in Figure A.4. The example shows the change of the indenter modulus after removal from the dry heat chamber used for artificial ageing (120 °C during 46 days). The change is due to the gradual restoration of the normal moisture content when subjected to the laboratory climatic conditions.

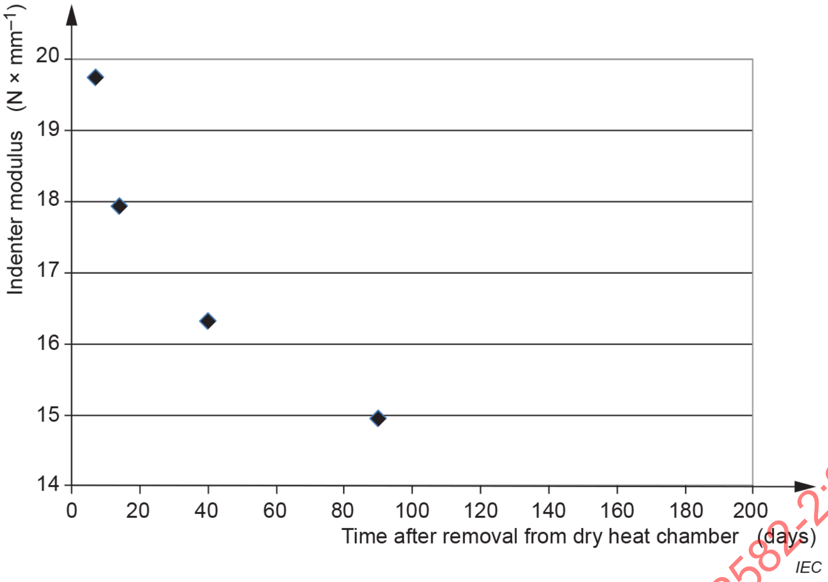
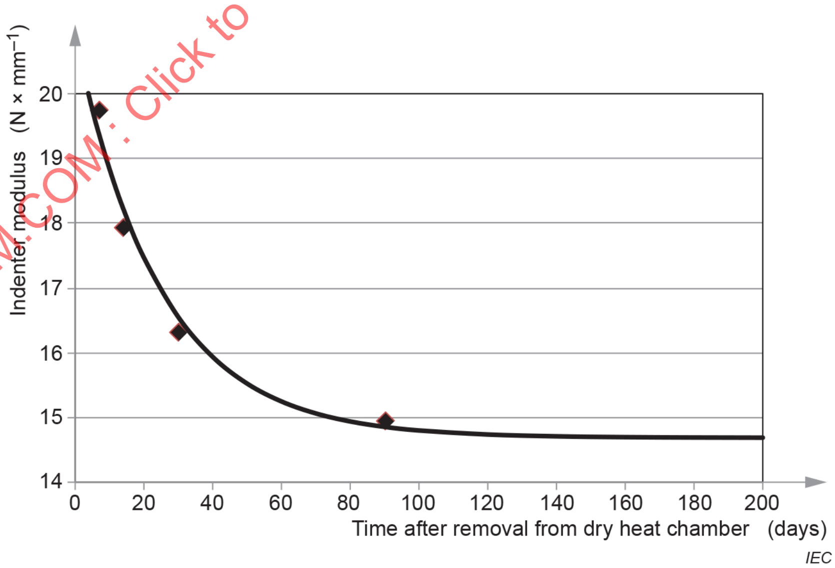


Figure A.4 – Example of change of indenter modulus value in laboratory conditions of a hygroscopic sample after removal from long-term exposure in a heat chamber

As shown in Figure A.4, moisture stabilisation in the laboratory after drying out of a hygroscopic sample can take a long time. It may not be practical to allow the time needed for the sample to attain moisture equilibrium before subjecting the sample to simulated design basis event conditions. A practical solution is to measure the indenter modulus versus time in the laboratory on one of the samples which has been subjected to the accelerated ageing whilst the other samples are subjected to simulated design basis event conditions. The resulting curve, similar to Figure A.4, can be used to estimate an indenter modulus value which represents normal moisture conditions. This value can then be used as the qualified condition.

By adapting a fitting decay curve, the indenter modulus value after restoration of the moisture content related to laboratory conditions can be estimated. This is illustrated in Figure A.5.



NOTE The decay curve has the form $Ae^{-kt} + B$, where t is the time after removal. The estimated value after restoration of the moisture content to laboratory conditions is 14,7 N·mm^{-1}.

Figure A.5 – Adaptation of a decay curve to the measured indenter modulus values in Figure A.4

Annex B
(informative)

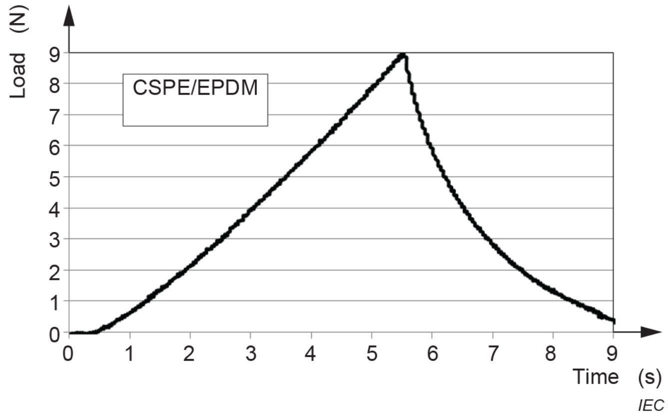
Example of a measurement report for indenter measurements in laboratory

The examples shown in Table B.1 and Figure B.1 are from the round-robin test programme carried out as part of an IAEA coordinated research programme on cable ageing.

Table B.1 – Example of a measurement report for indenter measurements in laboratory

Equipment ID	274 Cable FSSR 7X1
Material	Jacket: CSPE (2 mm) – blue. Insulation and conductors: 7 core EPDM on stranded Cu – grey (0,7 mm)
Pre-history	Artificially aged in dry heat test chamber. Method: IEC 60068 Test Ba. Ageing conditions: 120 °C for 42 days
Place and date of measurement	2 February 1998 Measurement in laboratory at ABB Atom, Västerås
Conditions for measurement	Time interval between removing the sample from the heat chamber until start of indenter measurement: > 30 days Measurement temperature: 21,5 °C
Instrument	OGDEN CI 96100007
Calibration	Before measurements according to the instrument manufacturer's instructions. Force calibrated with weights, probe velocity calibrated with stop-watch. See calibration report No xxxx
Measurement points	3 points on the jacket around the circumference at each of three cross-sections
Probe velocity	5,162 mm·min^{-1}
Maximum force	9 N
Mounting	Clamped in fixture provided by the instrument manufacturer with minimum force required to keep the cable in place. Fixture type large used.
Indenter modulus value	Mean value 23,39 N·mm^{-1}; Standard deviation 0,99 N·mm^{-1}. (After deletion of the highest and lowest values)

(Measurements at 8 points on the lead insulation (separately aged) showed a mean value of 29,35 N·mm^{-1} with a standard deviation of 2,34 N·mm^{-1}.)



NOTE The indenter modulus value was calculated from the slope between 1 N and 4 N by division by 5,162·60^{-1}.

Figure B.1 – Example of measured force versus time

Signature

Date

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~~IEC 60780, *Nuclear power plants – Electrical equipment of the safety system – Qualification*~~

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Edition 2.0 2022-11

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Nuclear power plants – Instrumentation and control important to safety – Electrical equipment condition monitoring methods – Part 2: Indenter measurements

Centrales nucléaires de puissance – Instrumentation et contrôle-commande importants pour la sûreté – Méthodes de surveillance de l'état des matériels électriques – Partie 2: Mesurages indenter

IEC/IEEE 62582-2:2022-11(en-fr)

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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NUCLEAR POWER PLANTS – INSTRUMENTATION AND CONTROL IMPORTANT TO SAFETY – ELECTRICAL EQUIPMENT CONDITION MONITORING METHODS –

Part 2: Indenter measurements

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC document(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation.

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IEC/IEEE 62582-2 was prepared by subcommittee 45A: Instrumentation, control and electrical power systems of nuclear facilities, of IEC technical committee 45: Nuclear instrumentation, in cooperation with Nuclear Power Engineering Committee of the IEEE, under the IEC/IEEE Dual Logo Agreement between IEC and IEEE. It is an International Standard.

This document is published as an IEC/IEEE Dual Logo standard.

This second edition cancels and replaces the first edition published in 2011, and its Amendment 1:2016. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) Modification of the title;
b) Consideration of publication of IEC/IEEE 60780-323.

The text of this International Standard is based on the following IEC documents:

FDIS	Report on voting
45A/1434/FDIS	45A/1444/RVD

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this International Standard is English.

This document was drafted in accordance with the rules given in the ISO/IEC Directives, Part 2, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

A list of all parts of IEC/IEEE 62582 series, under the general title *Nuclear power plants – Instrumentation and control important to safety – Electrical equipment condition monitoring methods*, can be found on the IEC website.

The IEC Technical Committee and IEEE Technical Committee have decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

INTRODUCTION

a) Technical background, main issues and organisation of this standard

This part of IEC/IEEE 62582 specifically focuses on indenter modulus methods for condition monitoring for the management of ageing of electrical equipment installed in nuclear power plants. The indenter method is commonly used to carry out measurements on cables (jackets, insulation) and O-rings.

This part 2 of IEC/IEEE 62582 contains detailed descriptions of condition monitoring based on indenter modulus measurements.

The IEC/IEEE 62582 series is issued with a joint logo which makes it applicable to the management of ageing of electrical equipment qualified to IEEE as well as IEC Standards.

IEC/IEEE 60780-323 includes the concept and role that condition based qualification could be used in equipment qualification as an adjunct to qualified life. In equipment qualification, the condition of the equipment for which acceptable performance was demonstrated is the qualified condition. The qualified condition is the condition of equipment, prior to the start of a design basis event, for which the equipment was demonstrated to meet the design requirements for the specified service conditions.

Significant research has been performed on condition monitoring techniques and the use of these techniques in equipment qualification as noted in NUREG/CR-6704, Vol. 2 (BNL-NUREG-52610) and JNES-SS-0903, 2009 and IAEA-TECDOC-1825:2017.

It is intended that this IEC/IEEE document be used by test laboratories, operators of nuclear power plants, systems evaluators, and licensors.

b) Situation of the current standard in the structure of the IEC SC 45A standard series

IEC/IEEE 62582-2 is the third level IEC SC 45A document tackling the specific issue of application and performance of indenter modulus measurements in management of ageing of electrical instrument and control equipment in nuclear power plants.

IEC/IEEE 62582-2 is to be read in association with IEC/IEEE 62582-1, which provides background and guidelines for the application of methods for condition monitoring of electrical equipment important to safety of nuclear power plants.

For more details on the structure of the IEC SC 45A standard series, see item d) of this introduction.

c) Recommendations and limitations regarding the application of this standard

It is important to note that this document establishes no additional functional requirements for safety systems.

d) Description of the structure of the IEC SC 45A standard series and relationships with other IEC documents and other bodies documents (IAEA, ISO)

The IEC SC 45A standard series comprises a hierarchy of four levels. The top-level documents of the IEC SC 45A standard series are IEC 61513 and IEC 63046.

IEC 61513 provides general requirements for instrumentation and control (I&C) systems and equipment that are used to perform functions important to safety in nuclear power plants (NPPs). IEC 63046 provides general requirements for electrical power systems of NPPs; it covers power supply systems including the supply systems of the I&C systems.

IEC 61513 and IEC 63046 are to be considered in conjunction and at the same level. IEC 61513 and IEC 63046 structure the IEC SC 45A standard series and shape a complete framework establishing general requirements for instrumentation, control and electrical power systems for nuclear power plants.

IEC 61513 and IEC 63046 refer directly to other IEC SC 45A standards for general requirements for specific topics, such as categorization of functions and classification of systems, qualification, separation, defence against common cause failure, control room design, electromagnetic compatibility, human factors engineering, cybersecurity, software and hardware aspects for programmable digital systems, coordination of safety and security requirements and management of ageing. The standards referenced directly at this second level should be considered together with IEC 61513 and IEC 63046 as a consistent document set.

At a third level, IEC SC 45A standards not directly referenced by IEC 61513 or by IEC 63046 are standards related to specific requirements for specific equipment, technical methods, or activities. Usually these documents, which make reference to second-level documents for general requirements, can be used on their own.

A fourth level extending the IEC SC 45 standard series, corresponds to the Technical Reports which are not normative.

The IEC SC 45A standards series consistently implements and details the safety and security principles and basic aspects provided in the relevant IAEA safety standards and in the relevant documents of the IAEA nuclear security series (NSS). In particular this includes the IAEA requirements SSR-2/1 , establishing safety requirements related to the design of nuclear power plants (NPPs), the IAEA safety guide SSG-30 dealing with the safety classification of structures, systems and components in NPPs, the IAEA safety guide SSG-39 dealing with the design of instrumentation and control systems for NPPs, the IAEA safety guide SSG-34 dealing with the design of electrical power systems for NPPs, the IAEA safety guide SSG-51 dealing with human factors engineering in the design of NPPs and the implementing guide NSS17 for computer security at nuclear facilities. The safety and security terminology and definitions used by the SC 45A standards are consistent with those used by the IAEA.

IEC 61513 and IEC 63046 have adopted a presentation format similar to the basic safety publication IEC 61508 with an overall life-cycle framework and a system life-cycle framework. Regarding nuclear safety, IEC 61513 and IEC 63046 provide the interpretation of the general requirements of IEC 61508-1, IEC 61508-2 and IEC 61508-4, for the nuclear application sector. In this framework, IEC 60880, IEC 62138 and IEC 62566 correspond to IEC 61508-3 for the nuclear application sector.

IEC 61513 and IEC 63046 refer to ISO 9001 as well as to IAEA GSR part 2 and IAEA GS-G-3.1 and IAEA GS-G-3.5 for topics related to quality assurance (QA).

At level 2, regarding nuclear security, IEC 62645 is the entry document for the IEC/SC 45A security standards. It builds upon the valid high level principles and main concepts of the generic security standards, in particular ISO/IEC 27001 and ISO/IEC 27002; it adapts them and completes them to fit the nuclear context and coordinates with the IEC 62443 series. At level 2, IEC 60964 is the entry document for the IEC/SC 45A control rooms standards, IEC 63351 is the entry document for the human factors engineering standards and IEC 62342 is the entry document for the ageing management standards.

NOTE 1 It is assumed that for the design of I&C systems in NPPs that implement conventional safety functions (e.g. to address worker safety, asset protection, chemical hazards, process energy hazards) international or national standards would be applied.

NOTE 2 IEC TR 64000 provides a more comprehensive description of the overall structure of the IEC SC 45A standards series and of its relationship with other standards bodies and standards.

NUCLEAR POWER PLANTS – INSTRUMENTATION AND CONTROL IMPORTANT TO SAFETY – ELECTRICAL EQUIPMENT CONDITION MONITORING METHODS –

Part 2: Indenter measurements

1 Scope

This part of IEC/IEEE 62582 contains methods for condition monitoring of organic and polymeric materials in instrumentation and control systems using the indenter measurement technique in the detail necessary to produce accurate and reproducible measurements. It includes the requirements for the selection of samples, the measurement system and measurement conditions, and the reporting of the measurement results.

The different parts of IEC/IEEE 62582 are measurement standards, primarily for use in the management of ageing in initial qualification and after installation. IEC/IEEE 62582-1 includes requirements for the application of the other parts of the IEC/IEEE 62582 series and some elements which are common to all methods. Information on the role of condition monitoring in the qualification of equipment important to safety is found in IEC/IEEE 60780-323.

This document is intended for application to non-energised equipment.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO, IEC and IEEE maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp
- IEEE Standards Dictionary Online: available at http://dictionary.ieee.org

3.1
indenter modulus
ratio between the changes in applied force and corresponding displacement of a probe of a standardised shape, driven into a material

Note 1 to entry: It is expressed in $N \cdot mm^{-1}$.

Note 2 to entry: The term “modulus” typically refers to the modulus of elasticity of a material which is defined as the ratio of the applied stress and the corresponding strain and is expressed in $N \cdot m^{-2}$ (Pa). However, in the use of the indenter, it has become common practice to use the term indenter modulus to describe the ratio of the change in applied force to material deformation and express it in $N \cdot mm^{-1}$.

4 Abbreviated terms and acronyms

DBE design basis event

IM indenter modulus

SiR silicone rubber

CSPE chlorosulphonated polyethylene

EPDM ethylene propylene diene monomer

XLPE crosslinked polyethylene

5 General description

A typical indenter uses an instrumented probe, which is driven at a fixed velocity into the material and includes a load cell or similar force-measuring device, connected to the probe, which measures the force necessary to maintain the constant velocity. The probe's displacement is measured by an appropriate transducer. The travel and force are purposely limited to protect the material from permanent damage. The indenter modulus is calculated by dividing the change in force by the corresponding displacement during inward travel.

6 Applicability, reproducibility and complexity

6.1 General

When organic and polymeric materials age, they often harden which will result in an increase of indenter modulus. Some materials, such as some formulations of butyl rubber, soften during thermal and/or radiation ageing. The purpose of monitoring changes in indenter modulus is to estimate degradation rates and levels induced by ageing.

6.2 Applicability

The indenter method is commonly used to carry out measurements on cables (jackets, insulation) and O-rings. Its use requires special fixtures depending on the geometry of the samples.

This method should only be applied to materials whose hardness changes monotonically with ageing.

The indenter method can be carried out on equipment with high integrity in a non-invasive manner. However, the process of performing indenter measurements on equipment in field should include controls to ensure that damage – from the probe or from handling in order to access suitable measurement points – has not been imparted to the equipment. The process should include correction of any equipment that has been damaged or suspected of incurring damage.

Measurements in the field require access to the exterior wall of the equipment. For field measurements on cables, this often limits the measurements to jacket materials. It can be possible to assess the condition of cable insulation from indenter measurements on its jacket if there is a known relationship between the ageing degradation of the jacket material and the degradation of the insulation. This relationship shall be justified to be valid and sufficiently sensitive to provide the valid monitoring through the life of the test object.

6.3 Reproducibility

Indenter modulus values can be influenced by variability in specimen dimensions and construction, temperature and moisture content of the specimen, stabilisation of the specimen, and contamination of the specimen. If measurements are made under excessive vibration, this can influence the measured value. The influence by variability in the specimen dimensions and construction is typically the case for measurements on cables, where the measurement point may be situated above a cavity beneath the jacket surface. The cross-section of typical cable core insulation can differ substantially from that of an ideal tube and can result in variability in the measured values of indenter modulus depending on where the measurement is made. These variations tend to be localised. Measurements shall be taken at several points on the equipment to compensate for these local variations (see 7.6).

An illustration of variations due to variability in specimen dimensions and construction is given in Annex A.

A good knowledge of the construction of the equipment is important before the selection of measurement positions is made. In the case of loosely constructed cables, the variability is expected to be high and it is important that the measurements on the jacket are made over a conductor rather than free space.

6.4 Complexity

The degree of complexity experienced during indenter modulus measurements in the field will often depend on cable accessibility. Existing instruments can be used in the field on cables that are accessible. In this case, data generation is rapid and measurements at a large number of points can be carried out over short time periods. Instruments can be configured such that data are generated and stored directly. Measurements on equipment with more complex geometries and limited accessibility can require the development of special fixtures. The same fixture shall be used for repeated indenter modulus measurements.

7 Measurement procedure

7.1 Stabilisation of the polymeric materials

An appropriate time period shall be allowed for the polymeric materials in recently manufactured equipment to stabilise before any condition monitoring or accelerated ageing programmes are carried out. The time period over which the polymeric materials stabilise is normally dependent on the processing additives and polymer composition. If manufacturers' stabilisation time data are not available, a period of 6 months should be allowed.

7.2 Sampling and measurement locations

Laboratory measurements of indenter modulus on samples selected from the field and indenter modulus measurements in the field only provide information on the status of the equipment at a specific location. Knowledge of the environmental conditions in representative areas during plant operation is a prerequisite for selecting locations. Since heating and radiation effects on equipment under test could be most apparent closest to the sources of heat and radiation, the choice of locations should consider capturing the potential for significant ageing effects near sources of heating and radiation. The position of the test locations and available information about the environmental time history of the locations selected shall be documented.

Sampling and measurement procedures shall comply with local instructions, taking into account the safety of personnel and equipment. Handling of equipment during measurement or removal of samples from the plant should be minimised, e.g. cables should not be bent more than necessary for the measurement or for the removal of the sample.

7.3 Conditions for measurement

The surface on which the measurements are made shall be cleaned of surface debris. In the field, it can be necessary to apply a dry wipe to remove accumulated dirt from the surface and prevent contamination of the indenter instrument. Under no circumstances shall solvents be used for surface cleaning.

The indenter modulus varies with the temperature and moisture content of the sample as shown in Annex A.

When measurements are carried out in the laboratory, e.g. after accelerated thermal ageing, they shall be made in a surrounding air temperature of (20 ± 5) °C and a relative humidity of 45 % to 75 %. Samples shall be allowed time to reach equilibrium with their surroundings before measurements are started.

NOTE Where the materials are hygroscopic, it is noted that the sample can be extremely dry after artificial accelerated ageing as a consequence of long-term exposure to high temperatures in an oven. For these materials, the values of indenter modulus measured can be significantly higher than for a sample in equilibrium with the laboratory atmosphere. This is particularly important for condition monitoring of hygroscopic insulation material when the final value of indenter modulus, on which qualified condition is based, is measured on completion of accelerated thermal ageing before the sample is subjected to a DBE test. Clause A.3 provides guidance on dealing with this specific concern.

It may not be possible to make field measurements in standard atmospheric conditions. In such cases the surrounding air temperature and the temperature at the surface at which the measurements are made shall be recorded.

Annex A shows a method for transformation of a measured indenter modulus to a corresponding modulus at a different temperature. In addition to reporting the temperature at which the value has been measured, it is recommended that the corresponding value at 20 °C be calculated and reported.

7.4 Instrumentation

The indenter functions by driving an instrumented probe at a fixed velocity into the material whilst a load cell or similar force-measuring device, connected to the probe, measures the applied force. The probe shall have the shape of a truncated steel cone with the geometry and dimensions shown in Figure 1. The probe's displacement is measured by an appropriate transducer. The point at which the tip of the probe is brought into contact with the material is sensed by a change in force. The probe's total displacement is normally limited to a fraction of a mm to prevent permanent deformation and to keep within the range of approximate linear proportionality between force and displacement. The indenter modulus (IM) is then calculated by dividing the change in force by the corresponding displacement during inward travel. The small displacements and loads that occur during this process prevent permanent effects on the material.

NOTE 1 Although the total displacement is limited, for some materials the relationship between force and displacement is still significantly non-linear.

Dimensions in millimetres

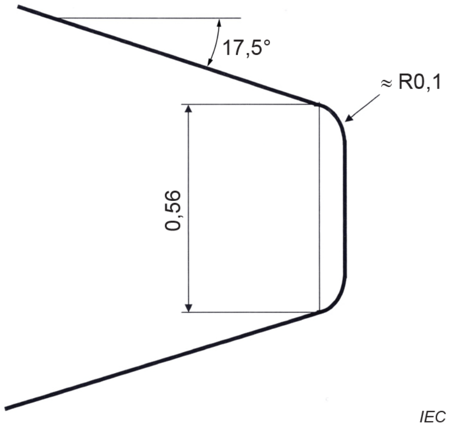


Figure 1 – Geometry and dimensions of the profile of the probe tip (truncated cone) used in the indenter

A typical indenter is a hand held instrument. At the head of the instrument, an appropriate clamping device holds a cable or wire securely in position so that the probe can be driven uniformly into the jacket or insulation of the cable or wire respectively. The probe is situated within the instrument and is attached to a sensitive load cell. A servo-controlled electric motor with appropriate gearing provides the capability to drive the probe towards the sample and the probe's position is measured by a transducer. A temperature sensor can be located close to the clamping device. The power and servo-control to the electric motor, and outputs from the load cell, transducer and temperature sensor are fed by cable into a separate controller which can be directly connected to a computer or capable of data storage in-situ which can be downloaded into a remote computer. Parameters such as probe velocity, and maximum load, and displacement are preloaded into the controller before the start of measurement. The instrument is also designed such that the cable clamp can be modified to allow calibration of the load cell using an appropriate weight and the probe travel using a dial gauge.

NOTE 2 When measuring on a wire with small diameters the result could be more non-linear in the beginning of the curve due to that only a part of the tip of the anvil have contact with the sample. This could influence the reproducibility with only small changes in the way to perform the measurement. See Figure 2.

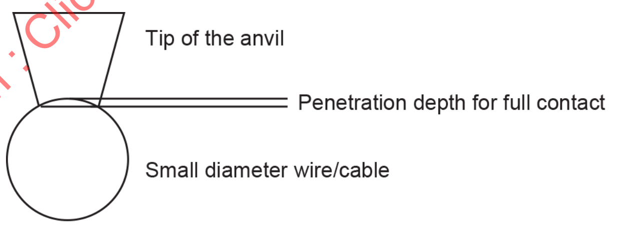


Figure 2 – Penetration depth for full contact on the tip of the anvil

7.5 Calibration and tolerances

The indenter and the measurement system shall be calibrated before each series of measurements in accordance with the manufacturer's instructions. The calibration shall be carried out on both the force sensor and probe velocity. The total error of force measurement shall be less than 3 % of the upper limit of the force range, including instrumentation tolerances as well as reading precision. The probe velocity shall be constant. The total measurement error of the required velocity shall be less than 2 %.

The user of the instrument shall have a defined process for visual inspection and measuring of the tip of the anvil. If wear or other damage to the tip of the anvil occurs to the extent that the dimensions are no longer according to Figure 1, then the anvil shall be replaced.

7.6 Selection of measurement points

In each of the selected locations for field measurements, measurements shall be carried out at several points and the mean value and standard deviation shall be reported. If the number of points is more than 7, the highest and lowest value shall be deleted before calculation of the mean value and the standard deviation. For measurements on cables, a minimum of three points around the circumference at each of three longitudinal positions shall be used. Where space is limited, it may not be possible to rotate around the cable circumference. In this case, a minimum of nine points shall be selected with a separation of 60 mm to 100 mm along the cable length.

If the measurement curve is not smooth maybe because of slipping due to low clamping force, the measurement value can be excluded and a new measurement be performed.

In the case of laboratory measurements on samples of cables, a minimum of three points around the circumference at each of three longitudinal positions shall be used. None of the measurement points shall be less than 100 mm from the ends of the sample.

For measurements on O-rings, a similar number of points shall be measured if the size of the O-ring allows.

7.7 Selection of probe velocity and maximum force

Before the start of the measurement, the test parameters shall be loaded into the measurement system. In particular, the required maximum load and maximum displacement should be set as limits to prevent damage to the equipment measured.

The probe velocity can have a significant influence on the measured value of indenter modulus. The probe velocity shall be 5 mm·min^{-1} to 5,2 mm·min^{-1}. The probe velocity that is selected shall be reported.

The maximum force that is selected needs to be a compromise between a value which is high enough to achieve reasonable resolution in the displacement axis and a value that is low enough to ensure that the probe does not damage the cable. For many polymeric insulation materials, a maximum force of 10 N is recommended. This will normally result in a probe penetration depth which is significantly less than 1 mm. For certain insulation materials, such as SiR, a maximum value lower than 10 N can be required to avoid excessive penetration.

NOTE Some measurement systems contain independent mechanisms to protect the equipment under test by limiting the probe force and travel distance.

7.8 Clamping

When carrying out measurements on cables, the measured value of indenter modulus can be strongly affected by variations in the force used to keep the cables securely in position within the clamp. In order to minimise these effects, the cable shall be clamped using the minimum force required to keep it in place. It is important that a consistent clamping methodology is used. Problems in clamping shall be included in the measurement report.

7.9 Determination of the value of the indenter modulus

The indenter modulus is determined by the slope of the force-displacement curve, and is expressed in N·mm^{-1}.

$$IM = (F_2 - F_1)/(d_2 - d_1) \quad (1)$$

where

IM is the indenter modulus;

F_i is the corresponding force value at displacement d_i.

IM shall be determined by using the values F_1 = 1 N and F_2 = 4 N, see Figure 3.

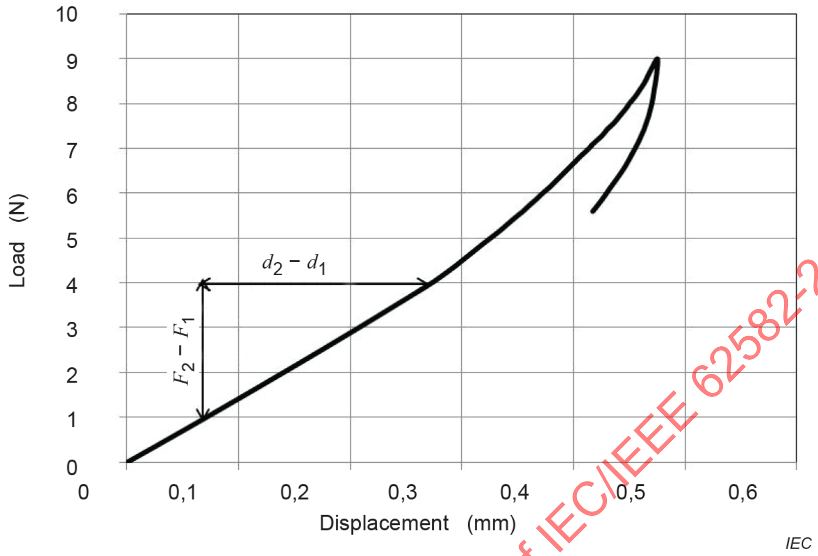


Figure 3 – Calculation of indenter modulus

NOTE Some instruments used for indenter measurements show the result in load versus time (in N·s^{-1}). The value of the indenter modulus in N·mm^{-1} is then calculated as the value in N·s^{-1} divided by the probe velocity in mm·s^{-1}.

7.10 Reporting

The measurement report shall as a minimum include the following items:

a) Identification of the equipment measured, including the material formulation. For selection of samples from the field or measurements in the field this shall include plant and location relative to heat and radiation sources (7.2).

b) Prehistory of the equipment. This can include:
   - indenter measurements on samples of new (un-aged) equipment: storage and time interval between production of the equipment sampled and start of the measurement (7.1);
   - indenter measurements on artificially aged samples: ageing conditions of the samples (7.3);
   - indenter measurements on naturally aged samples (e.g. field measurements): history of environmental conditions to which the sample has been subjected (7.2).

c) Place and date of the measurement (laboratory, on-site).

d) For laboratory measurement of samples subjected to artificial thermal ageing: time interval between removing the sample from the heat chamber until start of measurement (7.3).

e) Ambient and surface temperature at the time of measurement (7.3).

f) Other local conditions and situations encountered during measurement that can influence the results.

g) Measurement instrumentation, including software version (7.4).

h) Calibration procedure (7.5).

i) Measurement points (7.6).

j) Probe velocity (7.7).

k) Maximum force (7.7).

l) Mounting of the sample and problems in clamping (7.8).

m) For measurements in the field: observations on the condition of the equipment before and after indenter measurements (7.2). Also deviation from the demands in this document, due to limited space, for example.

n) Mean value and standard deviation of indenter modulus (after deleting the highest and lowest value), in N·mm^{-1} together with information on the force interval for which it has been determined (normally 1 N to 4 N) (7.6 and 7.9).

   If the indenter measurements are made at a temperature above 25 °C, it is recommended that the value referenced to 20 °C is also reported, calculated according to Annex A.

o) Diagram showing a typical force versus displacement curve.

p) Any other information of importance in interpretation of the measurement results in relation to the purposes of the measurements.

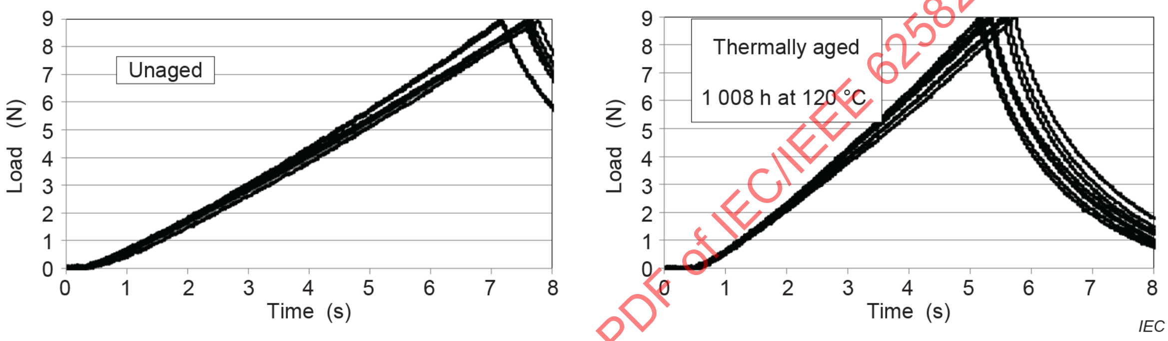
An example of a measurement report is given in Annex B.

Annex A
(informative)

Examples illustrating factors affecting the variation of the indenter modulus value

A.1 Example of influence of variability in equipment dimensions and construction

Figure A.1 illustrates the variations due to variability in equipment dimensions and construction, showing sets of data from indenter measurements at eight points on the jacket of a 7 core cable with jacket material CSPE and insulator material EPDM. The mean values and standard deviations of the indenter modulus measured were 15,57 N·mm^{-1} and 0,58 N·mm^{-1} for the unaged cable jacket, 23,21 N·mm^{-1} and 1,06 N·mm^{-1} for the thermally aged cable jacket.



NOTE The probe velocity was 5,2 mm·min^{-1} and the indenter modulus values were calculated from the slope between 1 N and 4 N by division by 5,2·60^{-1}.

Figure A.1 – Example of local variation of indenter modulus due to variation in equipment dimensions and construction

A.2 Examples of temperature dependence

These examples come from a study of the temperature dependence of the indenter values of three types of thermally aged cables:

– jacket and lead insulation materials CSPE,

– jacket material CSPE, lead insulation material XLPE,

– jacket and lead insulation materials EPDM.

The measurements were made at 9 (3×3) points on the jacket and the indenter modulus values were obtained from the slope of the force-distance curve between 1 N and 4 N. All cables had been thermally aged at 120 °C for 48 days. The measurements were made after temperature stabilisation at 21 °C, 35 °C and 50 °C.

Figure A.2 shows the results in terms of mean values and standard deviation of the indenter modulus.

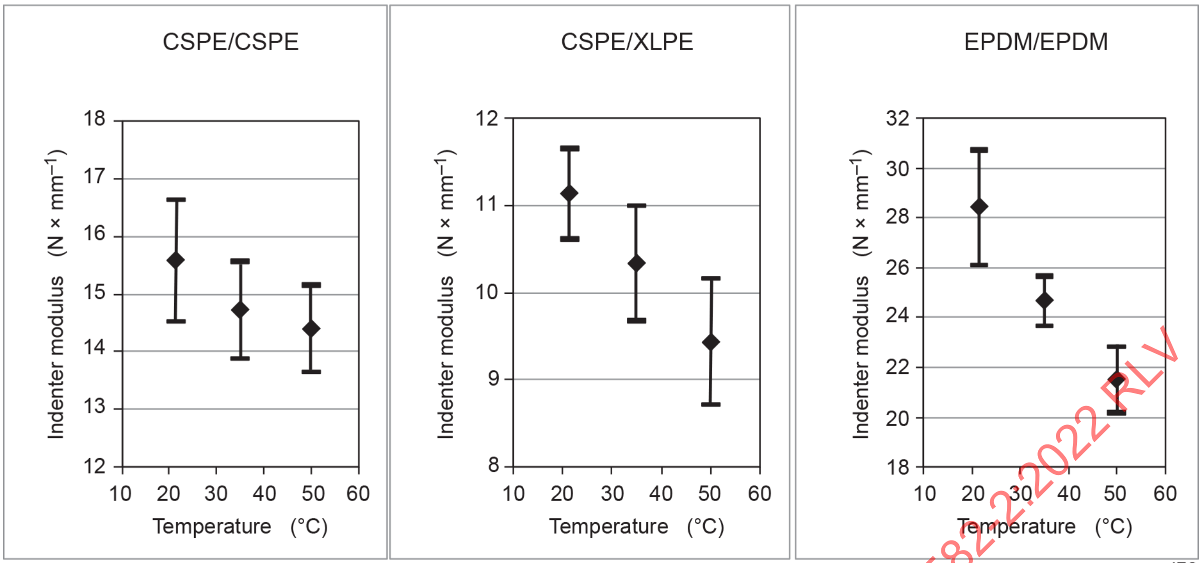


Figure A.2 – Indenter values measured at different temperatures

The results illustrate the temperature dependence of indenter modulus measurements.

In the case where indenter measurements are made at temperatures which differ substantially from the standard temperature for testing t_{ref} (20 °C), e.g. on site, normalisation to a value IM_{ref} at 20 °C can be made. The calculated value of IM_{ref} is given by the following empirical formula:

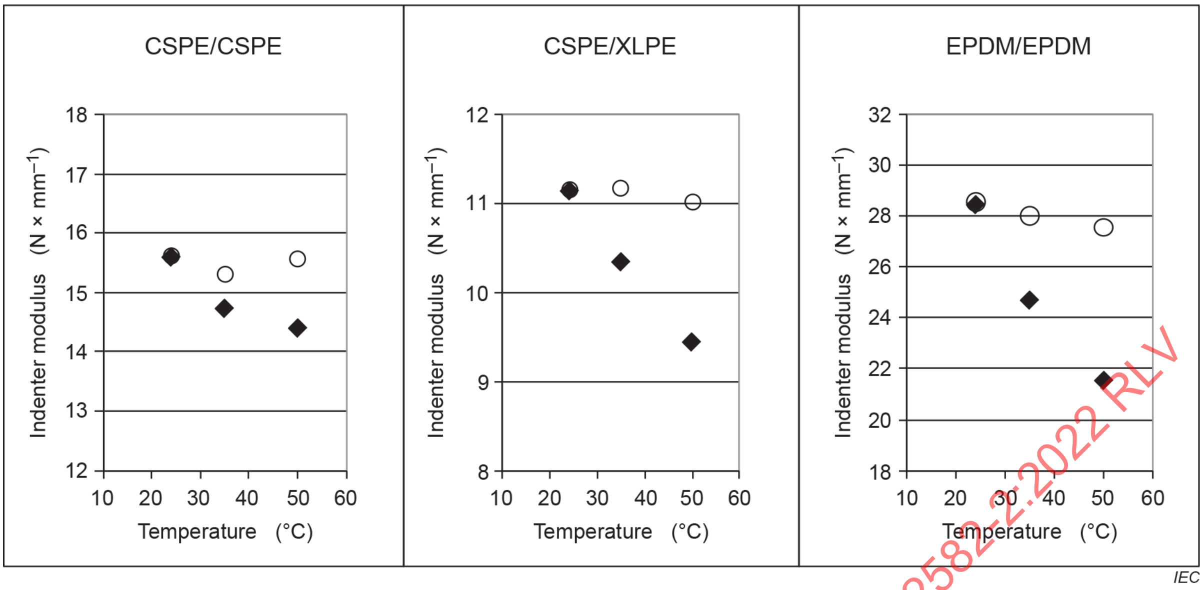
$$IM_{ref} = [1 + A \times (t - t_{ref}) / (t_1 - t_2)] \times IM_t$$

$$A = (IM_2 - IM_1) / [(IM_2 + IM_1)/2] \qquad \text{(A.1)}$$

where

t	is the temperature at which the measurement in the field is made;
IM_t	is the measured value of indenter modulus at temperature t;
IM_1 and IM_2	are the values of indenter modulus at two different temperatures t_1 and t_2 respectively from laboratory measurements made on the same material.

t_1 should be selected in the region of the highest temperature at which measurements in the field can be made, and t_2 should be in the region of 20 °C. Figure A.3 shows the mean values in Figure A.2 normalised according to formula (A.1).



Key

Diamonds represent the measured value.

Circles represent the normalised value.

Figure A.3 – Normalised indenter mean values

The normalisation works well over the measurement temperature interval 20 °C to 50 °C.

To summarise, the recommendation is:

- If practicable, to measure the indenter modulus after stabilisation to a standard laboratory temperature of 20 °C.
- If it is foreseen that measurements will be made on site at significantly higher temperature than standard laboratory temperature, e.g. for comparison with qualified condition, it is recommended that the relevant value of A is determined and reported by using measurements at two temperatures (laboratory temperature and one elevated temperature, close to what can be expected in site measurements). This should be carried out after the artificial laboratory ageing which forms part of the initial qualification testing.

A.3 Examples of effects on the indenter modulus from drying out after high temperature ageing

Most organic and polymeric materials currently used in-containment are not significantly hygroscopic. If hygroscopic materials are used, the influence of the moisture content of the material on indenter modulus can be significant and should be taken into account. An example of the influence for such a material is shown in Figure A.4. The example shows the change of the indenter modulus after removal from the dry heat chamber used for artificial ageing (120 °C during 46 days). The change is due to the gradual restoration of the normal moisture content when subjected to the laboratory climatic conditions.

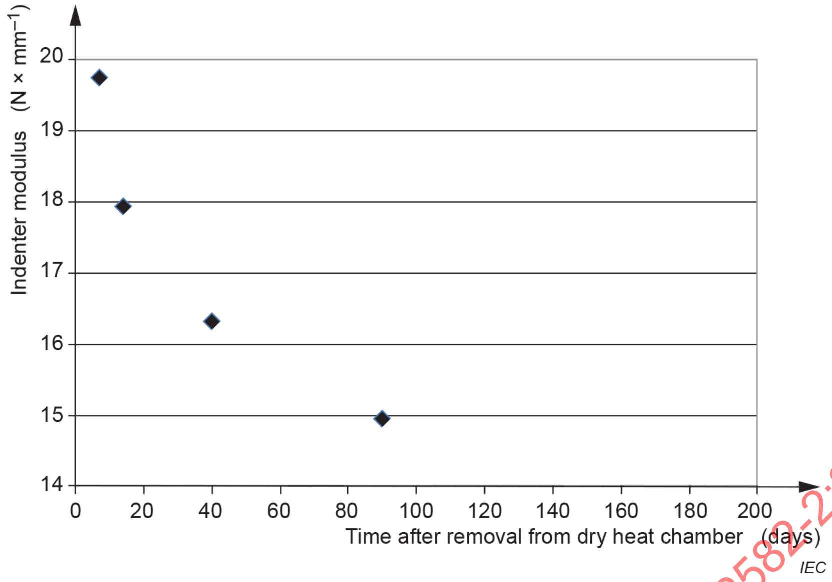
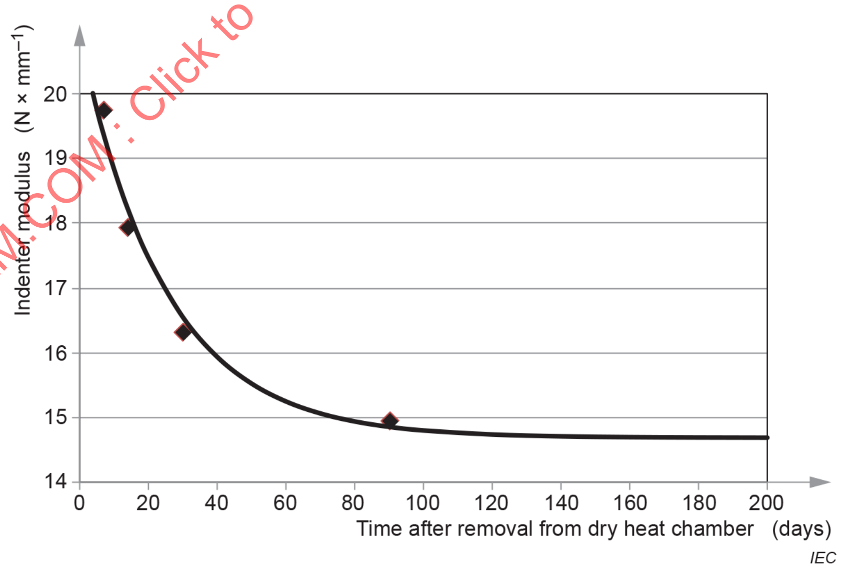


Figure A.4 – Example of change of indenter modulus value in laboratory conditions of a hygroscopic sample after removal from long-term exposure in a heat chamber

As shown in Figure A.4, moisture stabilisation in the laboratory after drying out of a hygroscopic sample can take a long time. It may not be practical to allow the time needed for the sample to attain moisture equilibrium before subjecting the sample to simulated design basis event conditions. A practical solution is to measure the indenter modulus versus time in the laboratory on one of the samples which has been subjected to the accelerated ageing whilst the other samples are subjected to simulated design basis event conditions. The resulting curve, similar to Figure A.4, can be used to estimate an indenter modulus value which represents normal moisture conditions. This value can then be used as the qualified condition.

By adapting a fitting decay curve, the indenter modulus value after restoration of the moisture content related to laboratory conditions can be estimated. This is illustrated in Figure A.5.



NOTE The decay curve has the form $Ae^{-kt} + B$, where t is the time after removal. The estimated value after restoration of the moisture content to laboratory conditions is 14,7 N·mm^{-1}.

Figure A.5 – Adaptation of a decay curve to the measured indenter modulus values in Figure A.4

Annex B
(informative)

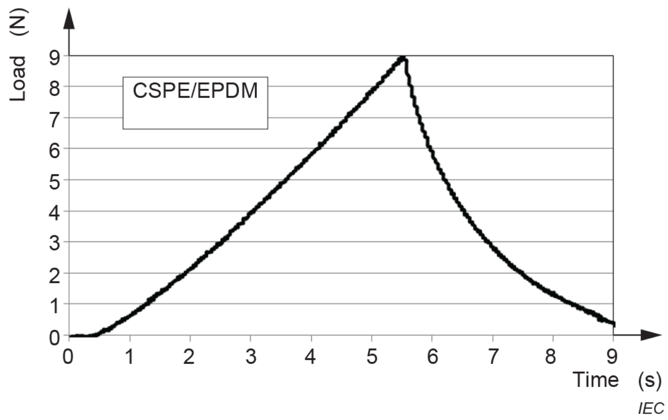
Example of a measurement report for indenter measurements in laboratory

The examples shown in Table B.1 and Figure B.1 are from the round-robin test programme carried out as part of an IAEA coordinated research programme on cable ageing.

Table B.1 – Example of a measurement report for indenter measurements in laboratory

Equipment ID	274 Cable FSSR 7X1
Material	Jacket: CSPE (2 mm) – blue. Insulation and conductors: 7 core EPDM on stranded Cu – grey (0,7 mm)
Pre-history	Artificially aged in dry heat test chamber. Method: IEC 60068 Test Ba. Ageing conditions: 120 °C for 42 days
Place and date of measurement	2 February 1998 Measurement in laboratory at ABB Atom, Västerås
Conditions for measurement	Time interval between removing the sample from the heat chamber until start of indenter measurement: > 30 days Measurement temperature: 21,5 °C
Instrument	OGDEN CI 96100007
Calibration	Before measurements according to the instrument manufacturer's instructions. Force calibrated with weights, probe velocity calibrated with stop-watch. See calibration report No xxxx
Measurement points	3 points on the jacket around the circumference at each of three cross-sections
Probe velocity	5,162 $mm \cdot min^{-1}$
Maximum force	9 N
Mounting	Clamped in fixture provided by the instrument manufacturer with minimum force required to keep the cable in place. Fixture type large used.
Indenter modulus value	Mean value 23,39 $N \cdot mm^{-1}$; Standard deviation 0,99 $N \cdot mm^{-1}$. (After deletion of the highest and lowest values)

(Measurements at 8 points on the lead insulation (separately aged) showed a mean value of 29,35 $N \cdot mm^{-1}$ with a standard deviation of 2,34 $N \cdot mm^{-1}$.)



NOTE The indenter modulus value was calculated from the slope between 1 N and 4 N by division by $5{,}162 \cdot 60^{-1}$.

Figure B.1 – Example of measured force versus time

Signature

Date

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SOMMAIRE

COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE

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CENTRALES NUCLÉAIRES DE PUISSANCE – INSTRUMENTATION ET CONTRÔLE-COMMANDE IMPORTANTS POUR LA SÛRETÉ – MÉTHODES DE SURVEILLANCE DE L'ÉTAT DES MATÉRIELS ÉLECTRIQUES –

Partie 2: Mesurages indenter

AVANT-PROPOS

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Cette édition inclut les modifications techniques majeures suivantes par rapport à l'édition précédente:

a) Modification du titre;
b) Prise en considération de la publication de l'IEC/IEEE 60780-323.

Le texte de cette Norme internationale est issu des documents suivants de l'IEC:

FDIS	Rapport de vote
45A/1434/FDIS	45A/1444/RVD

Le rapport de vote indiqué dans le tableau ci-dessus donne toute information sur le vote ayant abouti à son approbation.

La version française de cette norme n'a pas été soumise au vote.

La langue employée pour l'élaboration de cette Norme internationale est l'anglais.

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- supprimé,
- remplacé par une édition révisée, ou
- amendé.

INTRODUCTION

a) Contexte technique, questions importantes et structure de la présente norme

La présente partie de l'IEC/IEEE 62582 s'intéresse plus particulièrement aux méthodes de module indenter utilisées dans le cadre de la surveillance de l'état pour la gestion du vieillissement des matériels électriques installés dans les centrales nucléaires de puissance. La méthode indenter est communément utilisée pour effectuer des mesurages sur les câbles (gaines externes, isolant) et sur les joints toriques.

La présente partie 2 de l'IEC/IEEE 62582 contient une description détaillée de la surveillance de l'état fondée sur les mesurages réalisés par module indenter.

La série IEC/IEEE 62582 est publiée en double logo, ce qui la rend applicable pour la gestion du vieillissement des matériels électriques qualifiés tant dans le cadre des normes IEEE que dans celui des normes IEC.

La norme IEC/IEEE 60780-323 couvre le concept et le rôle complémentaire que peut jouer la qualification reposant sur l'état du matériel dans le cadre de la qualification des matériels au niveau de la durée de vie qualifiée. Dans le cadre de la qualification du matériel, l'état du matériel pour lequel des performances acceptables ont été prouvées correspond à l'état qualifié. L'état qualifié est l'état du matériel qui prévaut au début d'un évènement de dimensionnement, pour lequel il a été démontré que le matériel satisfaisait aux exigences de conception pour les conditions de service spécifiées.

Des recherches importantes ont été réalisées sur les techniques de surveillance de l'état des matériels et l'utilisation de ces techniques dans le cadre de la qualification desdits matériels, comme cela est indiqué dans les documents NUREG/CR-6704, Vol. 2 (BNL-NUREG-52610), JNES-SS-0903, 2009 et AIEA TECDOC-1825:2017.

L'objectif du présent document IEC/IEEE est d'être utilisé par les laboratoires d'essai, les exploitants de centrales nucléaires de puissance, les évaluateurs de systèmes et les régulateurs.

b) Position de la présente norme dans la structure de la série de normes du SC 45A de l'IEC

La norme IEC/IEEE 62582-2 est le document du SC 45A de l'IEC de troisième niveau qui traite du problème particulier de l'application et des performances des mesurages réalisés par module indenter dans le cadre de la gestion du vieillissement des matériels électriques et des matériels de commande utilisés dans les centrales nucléaires de puissance.

La norme IEC/IEEE 62582-2 doit être lue avec l'IEC/IEEE 62582-1, qui fournit les éléments de contexte et des lignes directrices pour l'application des méthodes de surveillance de l'état des matériels électriques importants pour la sûreté des centrales nucléaires de puissance.

Pour de plus amples informations sur la collection de normes du SC 45A de l'IEC, voir le point d) de la présente introduction.

c) Recommandations et limites relatives à l'application de la présente norme

Il est important de noter que le présent document n'établit pas d'exigence fonctionnelle supplémentaire pour les systèmes de sûreté.

d) Description de la structure de la série de normes du SC 45A de l’IEC et relations avec d’autres documents de l’IEC, et d’autres organisations (AIEA, ISO)

La série de normes du SC 45A de l’IEC comprend une hiérarchie de quatre niveaux. Les documents de niveau supérieur de la série de normes du SC 45A de l’IEC sont les normes IEC 61513 et IEC 63046.

L’IEC 61513 fournit des exigences générales relatives aux systèmes et matériels d’instrumentation et de contrôle-commande (I&C) utilisés pour accomplir les fonctions importantes pour la sûreté des centrales nucléaires de puissance (NPPs – *Nuclear power plants*). L’IEC 63046 fournit des exigences générales relatives aux systèmes d’alimentation électrique des NPP; elle couvre les systèmes d’alimentation électrique jusqu’à et y compris les alimentations des systèmes d'instrumentation et de contrôle-commande.

L’IEC 61513 et l’IEC 63046 doivent être étudiées ensemble et au même niveau. L’IEC 61513 et l’IEC 63046 structurent la série de normes du SC 45A de l’IEC et forment un cadre complet qui établit les exigences générales relatives aux systèmes et matériels d'instrumentation et de contrôle-commande, ainsi qu’aux systèmes d’alimentation électriques des centrales nucléaires de puissance.

L’IEC 61513 et l’IEC 63046 font directement référence aux autres normes du SC 45A de l’IEC pour les exigences générales relatives à des sujets particuliers, tels que la catégorisation des fonctions et le classement des systèmes, la qualification, la séparation des systèmes, la protection contre la défaillance de cause commune, la conception des salles de commande, la compatibilité électromagnétique, l’ergonomie, la cybersécurité, les aspects logiciels et matériels relatifs aux systèmes numériques programmables, la coordination des exigences de sûreté et de sécurité et la gestion du vieillissement. Il convient de considérer les normes référencées directement à ce deuxième niveau, ainsi que l’IEC 61513 et l’IEC 63046, comme un ensemble cohérent de documents.

Au troisième niveau, les normes du SC 45A de l’IEC, qui ne sont pas référencées directement par l’IEC 61513 ou l’IEC 63046, sont liées à des exigences spécifiques relatives à des matériels particuliers, ainsi qu’à des méthodes techniques ou à des activités spécifiques. Généralement ces documents, qui font référence aux documents de deuxième niveau pour les exigences générales, peuvent être utilisés seuls.

Un quatrième niveau qui est une extension de la série de normes du SC 45A de l’IEC correspond aux rapports techniques qui ne sont pas des documents normatifs.

La série de normes du SC 45A de l’IEC met en œuvre et détaille de manière cohérente les principes de sûreté et de sécurité, ainsi que les aspects fondamentaux fournis dans les normes de sûreté pertinentes de l'AIEA et dans les documents pertinents de la série sur la sécurité nucléaire (NSS – *nuclear security series*) de l'AIEA. Cette disposition inclut plus particulièrement les exigences SSR-2/1 de l’AIEA qui établissent les exigences de sûreté relatives à la conception des centrales nucléaires de puissance, le guide de sûreté SSG-30 de l’AIEA qui traite du classement de sûreté des structures, systèmes et composants des centrales nucléaires de puissance, le guide de sûreté SSG-39 de l’AIEA qui traite de la conception de l’instrumentation et du contrôle-commande des centrales nucléaires de puissance, le guide de sûreté SSG-34 de l’AIEA qui traite de la conception des systèmes d’alimentation électrique des centrales nucléaires de puissance, le guide de sûreté SSG-51 de l’AIEA qui traite de l’ergonomie dans la conception des centrales nucléaires de puissance et le guide de mise en œuvre NSS17 relatif à la sécurité informatique des installations nucléaires. La terminologie et les définitions utilisées pour la sûreté et la sécurité dans les normes produites par le SC 45A sont conformes à celles utilisées par l’AIEA.

L'IEC 61513 et l'IEC 63046 ont adopté une présentation similaire à celle de la publication fondamentale de sécurité IEC 61508, avec un cadre de cycle de vie global et un cadre de cycle de vie du système. En ce qui concerne la sûreté nucléaire, l'IEC 61513 et l'IEC 63046 interprètent les exigences générales des normes IEC 61508-1, IEC 61508-2 et IEC 61508-4, pour le secteur des applications nucléaires. Dans ce cadre, l'IEC 60880, l'IEC 62138 et l'IEC 62566 correspondent à l'IEC 61508-3 pour le secteur des applications nucléaires.

L'IEC 61513 et l'IEC 63046 font référence à l'ISO 9001, ainsi qu'aux documents AIEA GSR partie 2, AIEA GS-G-3.1 et AIEA GS-G-3.5 pour les sujets liés à l'assurance qualité (AQ).

Au niveau 2, concernant la sécurité nucléaire, l'IEC 62645 constitue le document chapeau pour les normes de sécurité produites par le SC 45A de l'IEC. Cette norme s'appuie sur les principes de haut niveau et les principaux concepts valides des normes de sécurité génériques, notamment l'ISO/IEC 27001 et l'ISO/IEC 27002, qu'elle adapte et complète pour répondre au contexte nucléaire et les coordonne avec la série IEC 62443. Au niveau 2, l'IEC 60964 constitue le document chapeau pour les normes du SC 45A de l'IEC portant sur les salles de commande, l'IEC 63351 constitue le document chapeau pour les normes portant sur l'ergonomie et l'IEC 62342 constitue le document chapeau pour les normes portant sur la gestion du vieillissement.

NOTE 1 Par hypothèse, des normes nationales ou internationales sont appliquées pour la conception des systèmes d'instrumentation et de contrôle-commande dans les centrales nucléaires de puissance qui mettent en œuvre des fonctions de sûreté conventionnelles (par exemple, pour assurer la sécurité des travailleurs et la protection des biens, répondre aux dangers chimiques et aux dangers liés à l'énergie procédé).

NOTE 2 L'IEC TR 64000 fournit une description plus complète de la structure globale de la série de normes produites par le SC 45A de l'IEC et de sa relation avec d'autres organismes de normalisation et d'autres normes.

CENTRALES NUCLÉAIRES DE PUISSANCE – INSTRUMENTATION ET CONTRÔLE-COMMANDE IMPORTANTS POUR LA SÛRETÉ – MÉTHODES DE SURVEILLANCE DE L'ÉTAT DES MATÉRIELS ÉLECTRIQUES –

Partie 2: Mesurages indenter

1 Domaine d'application

La présente partie de l'IEC/IEEE 62582 contient des méthodes de surveillance de l'état des matériaux organiques et polymères présents dans les systèmes d'instrumentation et de contrôle-commande, par l'utilisation de la technique de mesure indenter, selon un processus détaillé nécessaire pour obtenir des mesurages reproductibles et exacts. La présente partie comprend les exigences relatives à la sélection d'échantillons, au système et aux conditions de mesure, ainsi qu'au compte-rendu des résultats de mesure.

Les différentes parties de l'IEC/IEEE 62582 sont des normes de mesure, principalement destinées à être utilisées pour la gestion du vieillissement dans le cadre de la qualification initiale et après installation. L'IEC/IEEE 62582-1 comprend des exigences pour l'application des autres parties de la série IEC/IEEE 62582 et certains éléments communs à toutes les méthodes. L'IEC/IEEE 60780-323 fournit des informations concernant le rôle de la surveillance de l'état dans la qualification des matériels importants pour la sûreté.

Le présent document est applicable aux matériels qui ne sont pas sous tension.

2 Références normatives

Le présent document ne contient aucune référence normative.

3 Termes et définitions

Pour les besoins du présent document, les termes et définitions suivants s'appliquent.

L'ISO, l'IEC et l'IEEE tiennent à jour des bases de données terminologiques destinées à être utilisées en normalisation, consultables aux adresses suivantes:

- IEC Electropedia: disponible à l'adresse http://www.electropedia.org/
- ISO Online browsing platform: disponible à l'adresse http://www.iso.org/obp
- IEEE Standards Dictionary Online: disponible à l'adresse http://dictionary.ieee.org

3.1
module indenter
rapport entre les différences des forces appliquées pour obtenir une pénétration donnée d'une sonde de forme normalisée dans un matériau

Note 1 à l'article: Celui-ci est exprimé en $N{\cdot}mm^{-1}$.

Note 2 à l'article: Le terme “module” fait typiquement référence au module d'élasticité du matériau qui est défini comme le rapport des contraintes appliquées pour obtenir une déformation élastique donnée et qui est exprimé en $N.m^{-2}$ (Pa). Cependant, dans le cas de l'utilisation d'un poinçon, il est courant d'employer le terme “module indenter” pour décrire le rapport entre les forces appliquées pour déformer le matériau et d'exprimer celui-ci en $N.mm^{-1}$.

4 Abréviations et acronymes

EDD	évènement de dimensionnement
IM	(indenter modulus) module indenter
SiC	caoutchouc silicone
CSPE	(chlorosulphonated polyethylene) polyéthylène chlorosulphoné
EPDM	(ethylene propylene diene monomer) caoutchouc d'éthylène-propylène-diène
XLPE	(crosslinked polyethylene) polyéthylène réticulé

5 Description générale

Un poinçon type utilise une sonde instrumentée, qui est entraînée à une vitesse fixe dans le matériau et comprend un dynamomètre ou un dispositif similaire de mesure de la force, connecté à la sonde, qui mesure la force nécessaire pour maintenir la vitesse constante. Le déplacement de la sonde est mesuré par un transducteur approprié. La course et la force sont volontairement limitées pour protéger le matériau contre des dommages permanents. Le module indenter est calculé par le rapport de la variation de la force exercée et du déplacement correspondant pendant la course vers l'intérieur.

6 Applicabilité, reproductibilité et complexité

6.1 Généralités

Lorsque les matériaux organiques et polymères vieillissent, ils durcissent souvent, ce qui entraîne une augmentation du module indenter. Certains matériaux, tels que certaines formules de caoutchouc de butyle, se ramollissent au cours du vieillissement thermique et/ou par rayonnement. L'objectif de la surveillance de l'évolution du module indenter consiste à estimer les taux et les niveaux de dégradation induits par le vieillissement.

6.2 Applicabilité

La méthode indenter est communément utilisée pour effectuer des mesurages sur les câbles (gaines externes, isolant) et sur les joints toriques. Son utilisation exige des fixations particulières en fonction de la forme des échantillons.

Il convient d'appliquer cette méthode uniquement pour des matériaux dont la dureté varie de façon monotone par rapport au vieillissement.

La méthode indenter peut être appliquée pour des matériels qui présentent un niveau d'intégrité élevé de façon non intrusive. Cependant, il convient que le processus de réalisation de mesurages indenter sur des matériels sur le terrain comprenne les contrôles qui permettent de vérifier que les dommages – causés par la sonde ou dus aux manipulations nécessaires pour atteindre les points de mesure adaptés – n'ont pas dégradé le matériel. Il convient que le processus comprenne la réparation de tout matériel qui a été endommagé ou qui est susceptible de subir un dommage.

Les mesurages réalisés sur le terrain exigent un accès à la paroi externe du matériel. Concernant les mesurages sur les câbles réalisés sur le terrain, cette disposition limite souvent les mesurages aux matériaux de gainage externe des câbles. Il peut être possible d'évaluer l'état de l'isolant des câbles à partir des mesurages indenter réalisés sur sa gaine externe, s'il existe une relation connue entre la dégradation liée au vieillissement du matériau de gainage externe et la dégradation de l'isolant. La validité de cette relation doit être démontrée et elle doit être suffisamment sensible pour permettre une surveillance correcte tout au long de la durée de vie de l'objet en essai.

6.3 Reproductibilité

Les valeurs du module indenter peuvent être influencées par la variabilité des dimensions et de la construction des éprouvettes, ainsi que par la température, la teneur en eau, la stabilité et la contamination de ces dernières. Si des mesurages sont réalisés en présence de vibrations excessives, cela peut avoir une influence sur la valeur mesurée. L'influence liée à la variabilité des dimensions et de la construction des éprouvettes est généralement observée dans le cas de mesurages réalisés sur les câbles, avec lesquels le point de mesure peut être situé au-dessus d'une cavité présente sous la surface de la gaine externe. La section de l'isolant type d'un conducteur de câble peut être significativement différente de celle d'un tube théorique, ce qui peut, suivant l'emplacement auquel est effectué le mesurage, entraîner des variations au niveau des valeurs mesurées du module indenter. Ces variations tendent à être localisées. Les mesurages doivent être réalisés en plusieurs points du matériel afin de compenser ces variations localisées (voir 7.6).

L'Annexe A représente les variations dues à la variabilité des dimensions et de la construction des éprouvettes.

Une bonne connaissance de la constitution du matériel est importante avant de sélectionner les positions de mesure. Dans le cas des câbles à structure lâche, il est prévu que la variabilité soit élevée. De même, il est important que les mesurages sur la gaine externe soient effectués sur un conducteur plutôt que dans un espace libre.

6.4 Complexité

Le degré de complexité observé au cours des mesurages de module indenter sur le terrain dépend souvent de l'accessibilité des câbles. Des appareils de mesure existants peuvent être utilisés sur le terrain sur les câbles accessibles. Dans ce cas, la génération de données est rapide et les mesurages d'un grand nombre de points peuvent être effectués pendant de courtes durées. Les appareils de mesure peuvent être configurés de sorte que les données soient produites et stockées directement. Les mesurages effectués sur des matériels qui présentent des configurations plus complexes et une accessibilité limitée peuvent exiger le développement de fixations particulières. Les mêmes fixations doivent être utilisées pour des mesurages répétés du module indenter.

7 Procédure de mesure

7.1 Stabilisation des matériaux polymères

Une durée appropriée doit être prévue pour que les matériaux polymères des matériels fabriqués récemment se stabilisent avant que des programmes de surveillance de l'état ou de vieillissement accéléré ne soient réalisés. La durée pendant laquelle les matériaux polymères se stabilisent dépend normalement des additifs de traitement et de la composition des polymères. En l'absence de données du fabricant sur le temps de stabilisation, il convient de prévoir un délai de 6 mois.

7.2 Échantillonnage et emplacements de mesure

Les mesurages de module indenter réalisés en laboratoire sur des échantillons prélevés sur le terrain et les mesurages de module indenter réalisés sur le terrain fournissent seulement des informations sur l'état du matériel à un emplacement spécifique. La connaissance des conditions environnementales dans les zones représentatives pendant le fonctionnement de l'installation est une condition préalable au choix des emplacements. Étant donné que les effets de la chaleur et des rayonnements sur les matériels en essai peuvent être plus apparents à proximité des sources de chaleur et de rayonnement, il convient que le choix des emplacements tienne compte de la possibilité d'effets de vieillissement importants à proximité des sources de chaleur et de rayonnement. La position des emplacements d'essai et les informations disponibles concernant l'historique environnemental des emplacements choisis doivent être documentées.