AS 1018—1985

Australian Standard®

Partial discharge measurements

This Australian standard was prepared by Committee EL/7, Power Switchgear. It was approved on behalf of the Council of the Standards Association of Australia on 20 November 1984 and published on 4 April 1985.

The following interests are represented on Committee EL/7

- Australian British Chamber of Commerce
- Australian Electrical and Electronic Manufacturers Association
- Confederation of Australian Industry
- Electricity Supply Association of Australia
- Institution of Engineers, Australia
- Railways of Australian Committee
- Testing Authority

This Standard was issued in draft form for comment as DR 83217.

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First published	. . . .	1970
Second edition	. . . .	1985

PUBLISHED BY STANDARDS AUSTRALIA
(STANDARDS ASSOCIATION OF AUSTRALIA)
1 THE CRESCENT, HOMEBUSH, NSW 2140
ISBN 0 7262 3651 9

PREFACE

This edition of this standard was prepared by the Association's Committee on Power Switchgear to supersede AS 1018 — 1970, Recommendations for Partial Discharge Measurements.

This standard is identical with and has been reproduced from IEC 270(1981), Partial Discharge Measurements. Thus it does not have the same format as AS 1018 — 1970.

This standard applies to the methods of measurement of partial discharges in the insulating media of electrical equipment during tests principally with alternating voltage, however, it also covers special requirements for partial discharge test measurements during tests with direct voltage.

This standard is intended principally as a guide to the drafting of specifications for specific equipment.

For the purpose of this standard, the text of the IEC Publication should be modified as follows:

(a) *Clauses 4.3.6 and 6.4.1.* Both Clauses 4.3.6 and 6.4.1 have been slightly amended and for the convenience of users the amendments have been inserted directly into the text of the standard and this is indicated by a rule in the margin.

(b) *Technical Committee.* Where reference is made to 'the relevant Technical Committee' this should also be taken as a reference to the relevant equipment standard.

(c) *Decimal comma.* The decimal point should replace the decimal comma wherever it appears.

(d) *Cross-reference.* The reference to IEC Publications should be replaced by reference to Australian Standards, as follows:

Reference to IEC Publication		*Appropriate Australian Standard*		
IEC 60:	High voltage test techniques	AS 1931	High Voltage Testing Techniques	
IRC 60-2, Part 2:	Test Procedures		Part 1—	General Definitions, Test procedures and Measuring Devices

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PARTIAL DISCHARGE MEASUREMENTS

1. Scope

This standard applies to the measurement of partial discharges during tests with alternating voltage, but general terms, definitions and requirements are usually also applicable for measurement of partial discharges during tests with direct voltage. Some special characteristics of partial discharge measurements under direct voltage are given in a separate clause and necessary references are made throughout the text. This standard is intended principally as a general guide to the drafting of specifications for specific apparatus.

Measurements of partial discharges are made for the following main purposes:

— to verify that the test object does not exhibit partial discharges greater than a specified magnitude, at a specified voltage;

— to determine the voltage amplitude at which partial discharges of a specified low magnitude commence with increasing voltage and cease with decreasing voltage;

— to determine the magnitude of the specified discharge quantity at a specified voltage.

The partial discharges which are considered in this standard are localized electrical discharges in insulating media, restricted to only a part of the dielectric under test and only partially bridging the insulation between conductors. Discharges mostly occur in the form of individual pulses, which can be detected as electrical pulses in the external circuit connected to the test object. However, a more continuous form may also occur, the so-called pulseless discharge. This form will normally not be detected by the measurement methods described in this standard.

Partial discharges may occur in cavities in solid insulation, in gas bubbles in liquid insulation or between layers of insulation with different dielectric characteristics. They may also occur at sharp edges or points of metallic surfaces.

Even though they involve only small amounts of energy, partial discharges may lead to progressive deterioration of the dielectric properties of insulating materials; the definition and evaluation of such deterioration, however, is beyond the scope of this standard.

Partial discharge measurements on cables and on apparatus having windings, such as transformers, generators and motors, are complicated by attenuation, resonance and travelling wave phenomena. Special requirements for tests on these objects are only briefly dealt with.

This standard deals mainly with electrical measurements of partial discharges, but some reference is also made to non-electrical methods.

2. Object

The objects of this standard are:

— to define the terms used;

— to define the relevant quantities to be measured;

— to describe test and measuring circuits which may be used;

— to recommend some types of measurement and instrumentation suitable for particular applications;

— to recommend methods for calibration;

— to describe test procedures;

— to give some assistance concerning the discrimination of partial discharges from external interference.

3. Definitions

3.1 *Partial discharge*

A partial discharge, within the terms of this standard, is an electric discharge that only partially bridges the insulation between conductors. Such discharges may, or may not, occur adjacent to a conductor.

Note.— Partial discharges in gases around a conductor are sometimes referred to as "corona". This term should not be applied to other forms of partial discharges.

The general term "ionization" should not be used to denote the particular case of partial discharges.

3.2 *Quantities related to partial discharges*

3.2.1 *General*

Partial discharges occurring in any test object under given conditions may be characterized by different measurable quantities such as charge, repetition rate, etc. Quantitative results of measurements are expressed in terms of one or more of the specified quantities. For tests with direct voltage, see Clause 9.

3.2.2 *Apparent charge q*

The apparent charge q of a partial discharge is that charge which, if injected instantaneously between the terminals of the test object, would momentarily change the voltage between its terminals by the same amount as the partial discharge itself. The apparent charge is expressed in picocoulombs.

Notes *1.*— The apparent charge is not equal to the amount of charge locally involved at the site of the discharge and which cannot be directly measured.

2.— In practice, the waveform of the voltage appearing across the terminals of the test object due to the partial discharge itself may be different from that produced by the calibrating pulse. The apparent charge is considered to be that charge which, if injected between the terminals of the test object, will give the same reading on the measuring instrument as the partial discharge itself. Special cases are those in which the test objects include travelling wave or attenuation phenomena, see Appendix C.

3.2.3 *Repetition rate n*

The partial discharge pulse repetition rate n is the average number of partial discharge pulses per second measured over a selected time.

Note.— In practice, only pulses above a specified magnitude or within a specified range of magnitudes, may be considered. The results are sometimes expressed as cumulative frequency distribution curves of partial discharge magnitudes.

3.2.4 *Integrated quantities*

For particular purposes integrated quantities which are characterized by summations over a time interval T are in use. This time interval is often long compared with the duration of one cycle of an alternating voltage applied to the test object.

Examples of such quantities are:

— the average discharge current I,

this is the sum of the absolute values of the apparent charges during a certain time interval divided by this time interval;

— the quadratic rate D,

this is the sum of the squares of the apparent charges, during a certain time interval, divided by this time interval;

— the discharge power P,

this is the average power fed into the terminals of the test object due to partial discharges.

For particulars, see Appendix B.

3.3 *Specified partial discharge magnitude*

The specified partial discharge magnitude is the value of the partial discharge quantity stated in standards or specifications for the given test object at a specified voltage.

3.4 *Voltages related to partial discharges*

Voltage values during partial discharge tests are given by their peak values divided by $\sqrt{2}$ in the case of alternating voltages. The following voltages are of particular interest. For tests with direct voltages, see Clause 9.

3.4.1 *Partial discharge inception voltage U_i*

The partial discharge inception voltage U_i is the lowest voltage at which partial discharges are observed in the test arrangement, when the voltage applied to the object is gradually increased from a lower value at which no such discharges are observed.

In practice, the inception voltage U_i is the lowest voltage at which the partial discharge magnitude becomes equal to or exceeds a specified low value.

3.4.2 *Partial discharge extinction voltage U_e*

The partial discharge extinction voltage U_e is the lowest voltage at which partial discharges are observed in the test arrangement when the voltage applied to the object is gradually decreased from a higher value at which such discharges are observed.

In practice, the extinction voltage U_e is the lowest voltage at which the partial discharge magnitude becomes equal to or less than a specified low value.

3.4.3 *Partial discharge test voltage*

The partial discharge test voltage is a specified voltage, applied in a specified test procedure, during which the test object should not exhibit partial discharges exceeding a specified magnitude.

4. Test circuits and measuring instruments

4.1 *General requirements*

In this clause, various types of test circuits and instruments for the measurement of partial discharges are briefly described. Whatever type of test circuit and measuring instrument is used, they should be calibrated as specified in Clause 5 and should meet the requirements specified by the relevant Technical Committee (Clauses 6 and 7). The relevant Technical Committee shall specify the particular quantity or quantities to be measured. Any instrument measuring this quantity or quantities is in general considered acceptable. The Committee may also recommend a particular test circuit to be used. If not otherwise specified by the relevant Technical Committee, any of the test circuits mentioned in Sub-clause 4.2 and any of the instruments mentioned in Sub-clause 4.3 are acceptable.

For tests with direct voltages, see Clause 9.

Non-electrical methods of partial discharge detection are not recommended for quantitative measurements, but they are useful for special purposes, for example, discharge location. Some information is therefore given in Sub-clause 4.4.

4.2 *Test circuits*

Most circuits in use for partial discharge measurements can be derived from one or other of the three basic circuits, which are shown in Figures 1a, 1b and 1c, page 54; some variations of these circuits are shown in Figures 2 and 3, page 55. Each of these circuits consists mainly of:

— a test object which, in many cases, can be regarded as a capacitance C_a (see however, Appendix C);

— a coupling capacitor C_k or a second test object C_{al};

— a measuring circuit consisting of the measuring impedance Z_m (and sometimes a second impedance Z_{ml}), the connecting lead and the measuring instrument;

— sometimes an impedance or filter Z to prevent discharge pulses from being bypassed through the high-voltage supply and to reduce interference from the source.

The particular characteristics of the different circuit arrangements are considered in Appendix A.

Partial discharges in the test object cause charge transfer in the test circuit giving rise to current pulses through the measuring impedance. This impedance, in combination with the test object and coupling capacitor, determines the duration and shape of the measured voltage pulses. These pulses are further shaped and amplified in order to supply to a measuring instrument a value proportional to the apparent charge quantity.

4.2.1 *Measuring circuit characteristics*

Depending on the frequency range of the measurement, the measuring circuits can be classified into two groups: wideband and narrow-band. The wideband or narrow-band characteristics of the measuring circuit are normally determined by the instrument.

Characteristics of the measuring circuits are defined by the following parameters:

a) Lower and upper cut-off frequencies f_1 and f_2

The lower and upper cut-off frequencies f_1 and f_2 are the frequencies at which the response to a constant sinusoidal input voltage has fallen by a fixed amount, usually 3 dB, from the constant value in the case of wideband circuits and 6 dB from the peak value in the case of narrow-band circuits.

b) Resonance frequency f_o

When the responses show a resonance peak (narrow-band circuits or instruments) the corresponding frequency is called the resonance frequency f_o.

c) Bandwidth Δf

For both narrow-band and wideband instruments, the bandwidth is defined by:

$$\Delta f = f_2 - f_1$$

For wideband responses Δf is usually of the same order of magnitude as f_2 whereas it is substantially smaller then f_o for narrow-band responses.

d) Pulse resolution time

The pulse resolution time is the shortest time interval between two consecutive pulses which results in an amplitude error of not more than 10% due to superposition caused by the overlapping of the pulses.

The pulse resolution time is inversely proportional to the bandwidth of the measuring circuit.

4.2.2 *Scale factor of the test circuit k_c*

The scale factor k_c is the factor by which the reading of the instrument shall be multiplied to obtain the magnitude of the measured partial discharge quantity. The scale factor k_c is not the same as the scale factor k_i for the instrument alone. See Sub-clause 4.3.1.

4.2.3 *Measuring impedance*

The measuring impedance usually acts as a four-terminal network with a frequency response chosen to prevent the test supply frequency from reaching the instrument. This may be achieved in the case of a resistive impedance by connecting an inductor in parallel with the resistor, or, by connecting a capacitor in series between the measuring resistor and the connecting lead to the instrument. The measuring impedance may consist of a resistor, a resistor in parallel with a capacitor, a tuned circuit or a more complex filter design. For narrow-band measuring circuits, tuning of the measuring impedance to the measuring frequency of the instrument is often used.

4.2.4 *Coupling capacitor*

The coupling capacitor shall be of a low inductance design and its resonant frequency shall be not less than 3 f_2.

In addition, the coupling capacitor shall not exhibit any significant partial discharges at the test voltage.

4.3 *Measuring instruments*

Instruments available for partial discharge measurements may be classified in various ways. In Sub-clauses 4.3.1 to 4.3.7, their main requirements are summarized in accordance with the quantities to be measured (defined in Sub-clause 3.2).

Whatever other form of indication may be given by the measuring instrument, it is recommended that an oscilloscope should also be used as this assists in distinguishing between different types of partial discharges and between the discharges to be measured and extraneous disturbances.

See Clause 9 for the case of tests with direct voltages.

4.3.1 *Scale factor of the measuring instrument* k_i

The scale factor k_i is the factor by which the reading of the instrument shall be multiplied in order to obtain the magnitude of the discharge quantity injected into the instrument during its calibration.

4.3.2 *Instruments for the measurement of apparent charge* q

The current pulses due to partial discharges produce a signal at the terminals of the measuring impedance. For short duration current pulses, the signal produced is a voltage pulse whose peak value is proportional to the apparent charge of the test object.

The individual pulses may be displayed on a cathode-ray oscilloscope and the magnitude of the apparent charge can be determined by calibration. The pulses can be displayed on a linear time-base which is triggered, for example, by the discharge pulse or by the test voltage. It may also be convenient to display the pulses on an elliptical time-base which rotates synchronously with the test voltage frequency.

The magnitude of the apparent charge which is measured during an actual test is generally understood to be that associated with the largest repeatedly occurring pulse. The magnitude of the largest discharge pulses can be measured directly on the oscilloscope or by a suitable peak meter.

The resolution time of the instrument is acceptable if no error in amplitude measurement occurs due to overlapping of pulses when these are at least 100 μs apart. Resolution times much shorter than this are desirable, however, and can be obtained with available instruments. Errors may also occur due to the time constants of the peak meter if the pulse repetition rate is low.

Notes *1.*— Owing to the nature of the partial discharge, or to capacitive elements in the measuring circuit, the current pulses may be lengthened. Then, for the longer pulses, the apparent charge at the test object is proportional to the integral of the voltage pulse.

2.— The distribution of the repetition rates which are related to different pulse magnitudes can be determined using pulse counters (Sub-clause 4.3.3).

4.3.3 *Instruments for the measurement of pulse repetition rate n*

Any kind of pulse counter or rate meter indicating either the total number of pulses in a given time or the average number per second for all amplitudes measured or for given amplitude ranges can be used for measurement of the repetition rate, *n*, provided that the resolution time is sufficiently short. Usually, such counting instruments incorporate magnitude discriminators which suppress pulses below an adjustable predetermined magnitude.

Some care is needed to avoid obtaining more than one count per pulse if the pulses reaching the counter are oscillatory or bi-directional.

4.3.4 *Instruments for the measurement of average discharge current I*

In principle, instruments which measure the average value of the discharge current pulses after linear amplification and rectification will indicate, when suitably calibrated, the average discharge current *I* as defined in Sub-clause 3.2.4. Precautions are necessary to avoid undetected errors either due to amplifier overloading at low discharge repetition rates *n* or to overlapping of oscillatory pulses when *n* is large.

4.3.5 *Instruments for the measurement of quadratic rate D*

Instruments which measure the mean square value of the discharge magnitudes per second will indicate the quadratic rate *D* as defined in Sub-clause 3.2.4. The measurement can be made by passing the amplified pulses through a rectifier giving square law response and deriving the resulting mean d.c. component; or alternatively, it can be made by passing the pulses from a linear amplifier into a thermal detector. The overload characteristics of the instruments require special consideration.

4.3.6 *Arrangements for the measurement of discharge power P*

Different types of test circuits and instruments are possible for the measurement of discharge power. These are useful for test objects giving relatively high discharge magnitudes or repetition rates and are based on the measurement of the area of an oscilloscope display or on more sophisticated techniques. The calibration of such test circuits and instruments relies on the determination of the scale factors for applied voltage and apparent charge.

4.3.7 *Use of radio interference meters for the measurement of partial discharges*

Radio interference meters are frequency selective voltmeters. The instruments are primarily intended for measuring interference caused to reception of broadcast radio signals. Because of their special characteristics, radio interference meters do not directly indicate any of the partial discharge quantities defined in this standard (Sub-clause 3.2) but they give a general indication of discharge magnitude when used on the quasi-peak setting and calibrated according to Subclause 5.3. See also Appendix D.

The reading is sensitive to the repetition rate of the discharge pulses. It may be used provided that the pulse repetition rate is greater than 50 per second.

4.4 *Non-electrical methods of detection*

Non-electrical methods of partial discharge detection include acoustical and optical methods and also, where practicable, the subsequent observation of the effects of any discharges on the test object.

In general, these methods are not suitable for quantitative measurements of partial discharges and are essentially used to locate the discharges.

4.4.1 *Acoustic detection*

Aural observations made in a room with low noise level may be used as a means of detecting partial discharges.

Non-subjective acoustical measurements, usually made with microphones or other transducers and oscilloscopes, may also be useful, particularly for locating the discharges. Directionally selective microphones with high sensitivity above the audible frequency range are useful for locating corona discharges in air. Transducers in combination with oscilloscopes may also be used for locating discharges in oil-immersed equipment such as transformers; they may be either inside or outside the oil tank.

4.4.2 *Visual or optical detection*

Visual observations are carried out in a darkened room, after the eyes have become adapted to the dark and, if necessary, with the aid of binoculars of large aperture. Alternatively, a photographic record can be made, but fairly long exposure times are usually necessary. For special purposes, photo-multipliers or image intensifiers are sometimes used.

4.4.3 *Observations of tracking*

Tracking marks which have been left by discharges may give useful information on the location and extent of discharges when subsequent inspection is possible. Observation may be assisted by the use of ultra-violet light.

4.4.4 *Dissolved gases in oil*

The presence of partial discharges in oil-insulated apparatus may be detected in some cases by the analysis of the gases dissolved in the oil. This is usually a long duration phenomenon and the measurement is not associated with normal dielectric tests.

5. Calibration

5.1 *General*

Calibration involves two separate procedures; one is a complete determination of the characteristics of the measuring instrument itself including a detailed calibration and should be performed after major repairs or at least once per year, the other is a routine calibration of the instrument in the complete test circuit and should be performed before every test or, if many identical test objects are being tested then it may be performed at suitable intervals to be determined by the user. The latter calibration should include a verification that the instrument, as used in the test circuit, will be able to measure the minimum discharge level which has been specified by the relevant Technical Committee (Sub-clause 6.1).

Some methods for calibration are described in Sub-clauses 5.2 and 5.3; other methods may be used if their applicability is demonstrated.

5.2 *Determination of instrument characteristics*

The determination of the characteristics and the calibration of the measuring instrument should be made on all its ranges of measurement, in the conditions given by manufacturer specifications or by applicable standards.

The measuring impedance Z_m and any connecting cables should be included in the calibration of the instrument.

The following characteristics should be determined:

— variation of scale factor k_i to pulses of different amplitude at low repetition rate (about 100 per second);

— pulse resolution time, by applying pulses of constant magnitude at increasing repetition rate;

— lower and upper cut-off frequencies, f_1 and f_2;

— stability and accuracy of the calibrating devices.

The characteristics may be considered acceptable if their values have not changed by more than a few per cent in one year. In this case the calibration is usually not necessary at shorter intervals.

The error limits allowed for partial discharge measuring instruments are usually larger than in other measurements.

5.2.1 *Calibration of instruments measuring apparent charge q*

Calibration to determine the scale factor k_i of an instrument for the measurement of the apparent charge q of single partial discharges is carried out by passing short current pulses of any convenient but known charge magnitude, q_o, through the measuring impedance Z_m. Such pulses may be produced by means of a generator giving rectangular step voltages of amplitude U_o, in series with a small known capacitance C_o. Under these conditions, the calibration pulse is equivalent to a discharge of magnitude:

$$q_o = U_o C_o$$

In practice, it may not be possible to produce ideal step voltage pulses and, even though other waveforms having slower rise times and finite decay times may inject essentially the same amount of charge, the detection circuit responses will be different due to the different aurations of the corresponding current pulses.

The calibration pulse should have a rise time such that the duration of the current pulse through C_o is short compared with $1/f_2$ and this rise time shall be not more than 0.1 µs. A decay time in the range of 100 µs to some 1000 µs will usually be suitable.

As a source of calibration pulses with short fronts, small battery-operated pulse generators are in common use, employing either transistors or relays with mercury wetted contacts. When the main parameters (U_o, C_o) of the pulse generator cannot be separately checked, then a functional check shall be made by comparison with an arrangement comprising a step voltage generator in series with a known capacitance. Precautions should be taken to ensure that the measurement of this capacitance is not disturbed by the presence of stray capacitances.

5.2.2 *Calibration of instruments measuring integrated quantities*

The use of a generator similar to that described in Sub-clause 5.2.1 giving pulses of known charge and repetition rate is applicable for the calibration of instruments measuring the average discharge current or quadratic rate. A calibration procedure is given in Appendix B.

5.3 *Calibration of the instrument in the complete test arrangement*

The calibration of the instrument in the complete test arrangement is made to determine the scale factor k_c with the test object connected. This factor is affected by the circuit characteristics. The calibration should be repeated for each new test object, except in cases where tests are made on a series of similar test objects having capacitance values within ±10% of the mean value. This calibration need only be made at one or a few values of the measured quantity.

This calibration can be used to check the minimum discharge magnitude which can be measured. This minimum quantity is affected by the disturbance level and by the circuit characteristics (Clause 8).

Calibration of instruments measuring q, in the complete test arrangement should be made by injecting short-current pulses into the terminals of the test object, as shown in Figures 4a and 4b, page 56. In the case of the test circuit shown in Figure 4b, it is important to note that if the calibration pulses were applied between the high-voltage terminal and ground, errors are likely to be introduced.

The calibration pulses are obtained in the same manner and should meet the same requirements as given in Sub-clause 5.2. The calibration of the complete test arrangement is usually performed with the test object de-energized using a low voltage capacitor for C_o. Consequently, C_o must be removed before energizing the test circuit. Therefore, in order for the calibration to remain valid the calibrating capacitor must not be larger than about 0.1 ($C_a + C_k$). The calibration pulse is then equivalent to a discharge magnitude $q_o \cong U_o C_o$. In the case of tall test objects several metres in height, the injection capacitor C_o should be located close to the high-voltage terminal of the test object. In the same case, errors will also be caused by any stray capacitances C_s (see Figure 4), from the junction point of C_o and the step voltage generator to the high-voltage terminal unless these are negligible in comparison with that of C_o itself.

Despite the fact that a limitation of the bandwidth by the circuit itself is taken into account by the calibration, it is desirable that this limitation be avoided. Consequently, the resonance frequency f_o of a narrow-band detector should satisfy:

$$f_o \leq 0.3\, f_n$$

which can be checked by calculation:

where:

$f_n = \dfrac{1}{2\pi\sqrt{LC}}$

$C = \dfrac{C_a\, C_k}{C_a + C_k}$

$L = \alpha(h_1 + l + h_2)$: h_1 and h_2 are heights of test object and coupling capacitor and l is length of conductor between them

$\alpha = 10^{-6}$ H/m

Notes 1.— If the calculation shows resonance near the measuring frequency then the frequency response of the circuit has to be measured. When varying the measuring frequency over the range of $f_o \pm \Delta f$, no considerable change of the scale factor k_c should be observed.

2.— In the case of test objects with distributed parameters (such as cables), special calibration techniques may be necessary, see Appendix C.

6. Tests

6.1 *General requirements*

In order to obtain reproducible results in partial discharge tests, careful control of all relevant factors is necessary. The following clauses give the requirements applying to the test object itself and to the test voltage. Additional requirements, for special test conditions and methods of test, may be specified by the relevant Technical Committee. This Committee should also specify the quantity to be measured and the minimum measurable discharge magnitude required. Reference should be made to Sub-clause 8.4 for information on practical limits of minimum measurable magnitude. For the case of tests with direct voltages, see Clause 9.

6.2 *Conditioning of the test object*

Before being tested, a test object should undergo the conditioning procedure specified by the relevant Technical Committee.

If not otherwise specified, the surface of the insulators should be clean and dry since moisture or contamination on insulating surfaces can cause partial discharges. In addition, the test object should be at ambient temperature during the test. Mechanical, thermal and electrical stressing just before the test may affect the result of partial discharge tests. To ensure good reproducibility, a rest interval after previous stressing may be required before making partial discharge tests.

6.3 *Requirements for the test voltage*

For partial discharge tests with alternating voltages, the test voltages and the rate of rise shall comply with the respective requirements of I E C Publication 60-2: High-voltage Test Techniques, Part 2: Test Procedures, if not otherwise specified.

6.4 *Choice of test procedure*

The specification of procedures to be used for particular types of test and test object is the responsibility of the relevant Technical Committee. They include any preliminary conditioning process, the test voltage levels and frequency, sequence and durations of voltage application, and the relationship of partial discharge measurement tests to other dielectric tests.

To assist in preparing such test specifications, three examples of test procedures for alternating voltages are given in Sub-clauses 6.4.1 and 6.4.2.

6.4.1 *Determination of the partial discharge inception and extinction voltages*

A voltage well below the expected inception value is applied to the test object and gradually increased until discharges exceed a specified low magnitude. The test voltage at this specified magnitude is the partial discharge inception voltage. The voltage is then increased by about 10% and thereafter reduced to a value at which the discharges become less than the same specified magnitude. The test voltage at this discharge limit is the partial discharge extinction voltage. On some occasions this test may need to be repeated several times in order to obtain reproducible results. Note that, with some insulation systems, the extinction voltage may be influenced by the time during which the voltage is maintained above the inception voltage. In the case of repeated measurements of the inception and extinction voltages, both voltages may be affected.

Under no circumstances, however, shall the voltage applied exceed the rated withstand voltage applicable to the apparatus under test. Note that, in the case of high-voltage apparatus there is some danger of damage from repeated voltage applications approaching the rated withstand voltage.

6.4.2 *Determination of the partial discharge magnitude at a specified test voltage*

a) Measurement without pre-stressing

The partial discharge magnitude in terms of the specified quantity is measured at a specified voltage, which may be well above the expected partial discharge inception voltage. The voltage is gradually increased from a low value to the specified value and maintained there for the specified time. The partial discharge magnitude is measured at the end of this time, and thereafter the voltage is decreased and switched off.

Sometimes the magnitude of the discharges is also measured while the voltage is being increased or reduced or throughout the entire test period.

b) Measurement with pre-stressing

In an alternative procedure the test is made by raising the test voltage from a value below the specified partial discharge test voltage up to a specified voltage exceeding this voltage. The voltage is then maintained for the specified time and, thereafter, gradually reduced to the value of the partial discharge test voltage.

At this voltage level, the voltage is maintained for a specified time and at the end of this time the partial discharge magnitude is measured in a given time interval.

6.5 *Measurements on cables and on test objects with windings*

Some guidance for the measurement of partial discharges on cables and in test objects with windings will be found in Appendix C.

7. Measuring accuracy and sensitivity

Partial discharges are usually phenomena which are greatly affected by several factors and therefore are of relatively low reproducibility. Also, the measurements of partial discharges usually present larger errors than other measurements during high voltage tests. This should be taken into consideration when specifying partial discharge acceptance tests.

The measurements are also affected by the background noise which should be low enough to permit a sufficiently accurate measurement of the partial discharge; (normally less than 50% of the specified permissible partial discharge magnitude).

Pulses which are known to be caused by external disturbances can be disregarded. When low (≤10 pC) partial discharge magnitudes are specified for equipment acceptance tests, a background noise up to 100% of the specified value may be accepted.

Note.— The minimum partial discharge magnitude which can be measured in a particular test is in general limited by disturbances. However, where these are effectively eliminated by suitable screening or by using a balanced test circuit, the limits are usually determined by the internal noise level of the instrument itself and by the values of the test circuit parameters, especially C_a, C_k, Z_m and any capacitance C_m in parallel with Z_m. In general, the minimum measurable magnitude increases with increase in the values of C_a, C_m, $1/Z_m$ and the ratio C_a/C_k. The use of a matching transformer may increase the signal-to-noise ratio of the measurements for cases where the test object capacitance is very small or very large.

8. Disturbances

8.1 *Sources of disturbances*

Interference with the indication of partial discharge measuring instruments may be caused by disturbances which fall into two categories:

— Disturbances which occur even if the test circuit is not energized. They may be caused for example by switching operations in other circuits, commutating machines, high-voltage tests in the vicinity, radio transmissions, etc., including inherent noise of the measuring instrument itself. They may also occur when the power supply is connected but at zero voltage.

— Disturbances which only occur when the circuit is energized but which do not occur in the test object. These disturbances usually increase with increasing voltage. They may include for example partial discharges in the testing transformer, on the high-voltage conductors, in bushings (if not part of the test object), or disturbances caused by sparking of imperfectly earthed objects in the vicinity. They may also be caused by imperfect connections in the area of the high voltage, e.g. by spark discharges between screens and other high-voltage conductors, connected with the screen only for testing purposes. Disturbances may also be caused by higher harmonics of the test voltage within the bandwidth of the measuring instrument. Partial discharges or sparking contacts in the low voltage supply may also cause disturbances if transferred through the test transformer or through other connections to the measuring circuit.

For the case of disturbances with direct voltages, see Clause 9.

8.2 *Detecting disturbances*

The voltage-independent sources can be detected by a reading on the instrument when the test circuit is not energized. The value read on the instrument is a measure of these disturbances.

The voltage dependent sources of disturbances can be detected in the following manner; the test object is either removed or replaced by an equivalent capacitor having no significant partial discharges. The circuit should be recalibrated by the procedure given in Sub-clause 5.3. The circuit should now be energized up to the full test voltage.

If the disturbance level exceeds 50% of the maximum permissible discharge level of the test object, then measures should be introduced to reduce the disturbances. One or more of the methods described in Sub-clause 8.3 may be used to reduce the disturbances. It is incorrect to subtract the disturbance level from the measured partial discharge magnitude.

The use of an oscilloscope as an indicating instrument helps the observer to distinguish between discharges in the test object and external disturbances, such as background noise. It sometimes makes it possible to determine the type of discharges.

Non-electrical detection methods (Sub-clause 4.4) are often useful for locating corona on the high-voltage leads or elsewhere in the test area. They can also give independent confirmation of partial discharges in the test object.

8.3 *Reduction of disturbances*

8.3.1 *General*

Reduction of disturbances can be achieved by suitably grounding all conducting structures in the vicinity of the tests and by filtering the power supplies for the test and measuring circuits. The best reduction is achieved by testing in a shielded room where all electrical connections into the room are made through effective filters. Further reduction of disturbances can be achieved by the methods described in Sub-clauses 8.3.2 and 8.3.3.

8.3.2 *Balanced circuits*

The use of a balanced circuit, Figure 1c, page 54, often enables the observer to distinguish between discharges in the test object and discharges in other parts of the test circuit, or background noise, and also to compensate for the latter.

8.3.3 *Electronic processing and recovering of signals*

Generally and especially during industrial conditions, the sensitivity is limited by the presence of disturbances. Various electronic methods do exist, which may be used individually or in combination in order to separate the true partial discharge signal from the disturbances. They should only be used with special care. Some of these methods are described below.

a) Time window method

The instrument may be provided with a gate which can be opened and closed at pre-selected moments, thus either passing the signal or blocking it. If the disturbances occur during regular intervals the gate can be closed during these intervals. In tests with alternating voltage, the true discharge signal may occur only at regularly repeated intervals during the cycles of the test voltage. This can be used to open the gate only at these intervals. The time window method is particularly useful for tests with direct voltage where the test voltage is obtained by rectifying an alternating voltage.

b) Polarity discrimination methods

Signals originating from the test object may be distinguished from disturbances originating from outside the test circuit by comparing the polarity of the pulses across measuring impedances such as Z_m and Z_{m1}, Figure 1c. A logic system performs the comparison and operates the gate of the instrument, described in Item *a)* above, for pulses of the correct polarity and consequently only those pulses which originate from the test object are recorded.

c) Pulse averaging

Many disturbances in an industrial environment are random whereas true discharges recur at approximately the same time in each cycle of applied voltage. It is therefore possible to greatly reduce the relative level of randomly occurring disturbances by using modern signal-averaging techniques.

d) Frequency selection

Broadcast radio interference is limited to discrete bands but will still affect broadband discharge detectors if the transmission frequency falls within the frequency band of the instrument. To reduce this type of interference the gain of the instrument amplifier can be reduced by bandstop filters tuned to the frequencies where the disturbances occur. Alternatively, narrow-band instruments can be used which are tuned to a frequency at which the interference level is negligible.

8.4 *Disturbance levels*

No definite values for the magnitudes of disturbances can be given, but as a general guide disturbances equivalent to individual discharges of some hundreds of picocoulombs may be encountered in unscreened industrial testing areas, especially in the case of test circuits of large physical dimensions. By the use of balanced test circuits, such disturbances may be considerably reduced.

In shielded test rooms, with effective connecting of all conducting structures to the screen and with adequate precautions to suppress disturbances from the power supply and from other electrical systems, the ultimate limit of measurement is that of the measuring arrangement itself or that given by minor imperfections in the screening, grounding or filtering. For practical applications today, the lowest measurable value is about 1 pC.

9. Special requirements for partial discharge measurements during tests with direct voltage

9.1 *General*

There are several significant differences between partial discharge phenomena during tests with direct voltage and those with alternating voltage, particularly for tests on solid and liquid insulations and combinations of these. For gaseous insulation, these differences may be negligible.

Some of these differences are summarized as follows:

— The repetition rate for direct voltage can be very low due to the fact that the time interval between individual pulses at direct voltage is determined by the electrical time constant of the materials involved, while for alternating voltage it is determined by the frequency of the test voltage.

— The voltage distribution within the insulation materials will be determined by the resistivities when the voltage is constant, while during voltage variations it will be essentially determined by the dielectric constants.

After a change of the voltage level, either increase or decrease, there will be a charge redistribution process which normally has a fairly long duration. The same applies to a polarity reversal.

— The partial discharge behaviour of a test object may also be considerably influenced by such parameters as ripple on the direct voltage and temperature.

With regard to these phenomena further information concerning that given in Clauses 3 to 8 is given below.

9.2 *Quantities related to partial discharges*

In general, quantities such as apparent charge *q* and repetition rate *n* are also applicable to tests with direct voltages. However, there is no experience available concerning the use of integrated quantities for such tests.

9.3 *Voltages related to partial discharges*

Voltage values during partial discharge tests are given by their mean values in the case of direct voltages.

9.3.1 *Partial discharge inception and extinction voltages*

The partial discharge inception and extinction voltages may be difficult to determine during tests with direct voltages as they are dependent on factors such as the voltage distributions under variable voltages.

Under certain conditions the partial discharges may continue even after removal of the test voltage. This is valid particularly for solid and liquid insulation and combinations of these.

9.3.2 *Partial discharge test voltage*

The partial discharge test voltage is defined similarly to that for alternating voltage. Usually, only discharge magnitudes above a certain repetition rate are considered, however, single high magnitude pulses occurring infrequently may be of importance.

9.4 *Test circuits and measuring instruments*

In general, test circuits and measuring instruments used during tests with alternating voltages may also be used with direct voltages. However, it is recommended that pulse counting devices be used as a complement.

When the pulse repetition rate *n* is low, counting devices which display the number of discharges in different, selectable magnitude ranges over each time interval are useful.

9.5 *Tests*

9.5.1 *Requirements for the test voltage*

For partial discharge tests with direct voltages, the test voltages and the rate of rise shall comply with the respective requirements of I E C Publication 60-2, if not otherwise specified by the relevant Technical Committee.

9.5.2 *Choice of test procedure*

The procedures described for alternating voltage to determine the inception and extinction voltages are generally not applicable for tests with direct voltage as the stress on the dielectric during voltage rise and decrease is different from that during the period when the voltage is constant.

There is no generally accepted method for the determination of the partial discharge magnitude during tests with direct voltage. Whatever method is used, it is important to note that the partial discharge magnitude at the beginning of the voltage application may be different from its magnitude after a considerable time at the same test voltage.

9.6 *Disturbances*

The information given in Clause 8 is also applicable for tests with direct voltages. However, in this case a particular type of regularly repeated disturbance may occur which is related to the transition of current in the rectifier elements of the direct voltage source.

APPENDIX A

TEST CIRCUITS

Test circuits for the measurement of partial discharges either have the measuring impedance connected in series between the test object and ground or the measuring impedance is connected across the test object by means of a suitable coupling capacitor. With the series connection, some of the partial discharge currents may bypass the measuring impedance if the test object is not encased in such a manner as to ensure that all of the currents are collected and forced to flow through the measuring impedance.

There are three basic circuits from which all other test circuits for the detection and measurement of partial discharges are derived. These three circuits, which are shown in Figures 1a, 1b and 1c, page 54, are briefly described below.

Figure 1a

The measuring impedance in this circuit is placed at the earth side of the coupling capacitor. This arrangement has the advantage of being suitable for testing objects having one earthed terminal, the test object being connected directly between the high-voltage source and earth. The impedance *Z* between the test object and the high-voltage source serves to attenuate disturbances from the high voltage source. It also increases sensitivity in the measurements by providing blocking of the pulses from the test object which would otherwise be bypassed through the source impedance.

Figure 1b

In this circuit, the measuring impedance is placed at the earth side of the test object. The low-voltage side of the test object shall therefore be isolated from earth.

Note.— A circuit is sometimes used which is similar to that shown in Figure 1b, but in which, the function of C_k is performed by the stray capacitances. This arrangement may be suitable if the capacitance of the test object is small compared with the stray capacitance to earth. It may also be satisfactory if the terminal capacitance of the testing transformer is at least of the same order as C_a, provided that *Z* is omitted.

Figure 1c

The arrangement shown comprises a balanced circuit in which the instrument is connected between the impedances Z_m and Z_{m1}. The low voltage side of the test object and the coupling capacitance must both be isolated from earth. Their capacitances need not be equal but should preferably be of the same order, and for the best results their dielectric loss factors particularly in relation to their frequency dependence should be similar. The circuit has the merit of partially rejecting external disturbances. To adjust this rejection an artificial discharge source may be coupled between the high voltage terminal and earth. The impedance Z_m or Z_{m1} is then adjusted until a minimum reading of the instrument is obtained. Reduction ratios of from 3 (for totally unequal test objects) to 1 000 or even higher (for identical, well screened test objects) are possible.

Figure 2

From these basic circuits, many variations can be derived. The arrangement shown in Figure 2, page 55, applicable to test objects fitted with capacitance graded bushings, is equivalent to that of Figure 1a except that the bushing capacitance is used in place of the coupling capacitor C_k. If the bushing has a tapping, the measuring impedance is connected to this terminal; in this case, a relatively large capacitance C_m appears across the measuring impedance and may affect the sensitivity of the measurement.

Figure 3

This arrangement, page 55, shows a test circuit in which the test voltage is induced in the test object for example a power transformer or an instrument transformer. In principle, it is equivalent to the arrangement, shown in Figure 1a, page 54.

APPENDIX B

INTEGRATED QUANTITIES

The integrated quantities are related to the apparent charge q and the repetition rate n as follows when T is a reference time interval:

Average discharge current I

$$I = \frac{1}{T}\left[|q_1| + |q_2| + ... |q_m| \right]$$

The average discharge current is expressed in coulombs per second or in amperes. In some cases the time interval is one cycle and the quantity is referred to as total apparent charge per cycle.

Quadratic rate D

$$D = \frac{1}{T}\left[q_1^2 + q_2^2 + ... q_m^2 \right]$$

The quadratic rate is expressed in (coulombs)^2 per second.

Calibration of instruments measuring I or D in the complete test arrangement is made in a similar way to that described in Sub-clause 5.3 for the measurement of q. The repetition rate of the generator should be lower than the bandwidth of the measuring instrument. This requirement is generally met if the repetition rate corresponds to a pulse interval greater than the resolution time, which however, is not necessary for measuring the quadratic rate. In addition, the pulse repetition rate n must be known. If the pulses are derived from a rectangular voltage generator of fundamental frequency f_g and if both positive and negative current pulses are used, the repetition rate n will be equal to $2f_g$. Under these conditions the instrument reading corresponds to an average discharge current:

$$I = 2\, f_g\, U_o\, C_o$$

and a quadratic rate:

$$D = 2\, f_g\, (U_o\, C_o)^2$$

Discharge power P

$$P = \frac{1}{T}\left[q_1 U_1 + q_2 U_2 + ... q_m U_m \right]$$

where U_1, U_2, ..., U_m are instantaneous values of the test voltage at the instant of discharges q_1, q_2, ..., q_m.

The discharge power is expressed in watts.

APPENDIX C

MEASUREMENTS ON CABLES AND ON TEST OBJECTS WITH WINDINGS

In principle, any of the test circuits described in Appendix A can be used for test objects with windings and for cables that is for test objects with distributed capacitive and inductive elements. For some of these test objects, the test voltage may be induced; for example the high-voltage winding of a transformer may be excited from the low-voltage winding (Figure 3, page 55).

A detailed treatment of partial discharge measurements on objects with distributed elements is beyond the scope of this standard. The following points, however, are of special importance and are particularly drawn to the attention of the relevant Technical Committees.

Attenuation phenomena

Due to attenuation within windings or along cables, the magnitude which is recorded at a terminal of the test object may differ in magnitude from that at the point where it originates.

Resonance phenomena, reflections

The magnitude recorded at a terminal of a winding or cable under test may be modified by resonance phenomena or by reflections at the terminals. This is especially important if the instrument used has a narrow-band frequency response. Reflection phenomena (for example, in cables) can be taken into account using special calibration techniques such as double pulse generators.

Impedance characteristics

A test object with windings does not behave as a simple capacitance C_a, but often has the characteristics of a surge impedance, generally with some parallel lumped capacitance.

Location of discharges

Various methods can be used to locate partial discharges in test objects with windings or in cables. Some of these methods are based on simultaneous measurements at two or more terminals of the test object. Non-electrical methods (see Sub-clause 4.4) may also be applicable.

APPENDIX D

THE USE OF RADIO INTERFERENCE METERS FOR THE MEASUREMENT OF PARTIAL DISCHARGES

Requirements for instruments in common use for radio interference measurements are given in various specifications. Their response is generally determined by tuned bandpass filters, having a specified narrow bandwidth and variable midband frequency, and by a quasi-peak measuring circuit with specified charging time constant τ_1 and a discharging time constant τ_2. The indicating meter is a moving coil instrument, critically damped and having a mechanical time constant τ_3.

The characteristic of the instrument makes it respond basically to the charge of an input current pulse. Due to the quasi-peak measuring circuit of this instrument, impulses having the same charge but a higher repetition rate result in a higher reading on the instrument.

The meter reading U_r, depends on both the partial discharge magnitude q and the repetition rate n. For short regularly repeated pulses, the scale factor, k_i, of the instrument is given by:

$$k_i = \frac{1}{f(N) \cdot \Delta f \cdot Z_m}$$

where:

$f(N)$ = non-linear function of N (see Figure 5, page 56)

Δf = instrument bandwidth

Z_m = value of a purely resistive measuring impedance

q can be determined from $q = k_c \cdot U_r$ since k_c is proportional to k_i and is established during calibration of the complete test arrangement.

The reading can thus be considered to be approximately proportional to the magnitude q and to the instrument bandwidth. It may not in practice be proportional to Z_m if this has stray capacitance or inductance. The factor $f(N)$ is not strictly applicable if the discharge pulses are irregularly distributed in time.

One such instrument, designed as a quasi-peek voltmeter, is described in C.I.S.P.R. Publication 16: C.I.S.P.R. Specification for Radio Interference Measuring Apparatus and Measurement Methods. This specifies a bandwidth Δf of 9 kHz at 6 dB and time constants of τ_1 = 1 ms, τ_2 = 160 ms and τ_3 = 160 ms. For the measurement of radio interference, the instrument is calibrated using a sinusoidal voltage at the frequency to which the instrument is tuned and the interference voltage is conventionally expressed as the r.m.s. value of an equivalent sinusoidal voltage. Short and constant pulses of 0.158 μVs applied to the instrument with a regular repetition rate of 100 per second should give the same reading as a sine-wave input of 1 000 μV r.m.s. at the tuned frequency. The variation of the reading with repetition rate N for this instrument is shown in Figure 5.

The above-mentioned C.I.S.P.R. publication gives specifications for the use of this instrument for measurement of the radio noise voltage generated by high-voltage equipment. Two test circuits are described therein which agree essentially with those of Figures 1a and 1b, page 54, and may also be used for the measurement of partial discharges with certain precautions.

It should be noted that the curve of Figure 5, page 56, applies to regularly repeated pulses only. Consequently, if a radio interference meter is to be used for partial discharge measurements, it should be calibrated and checked in the actual circuit according to Sub-clause 5.3. It is recommended that this be done by the application of regularly repeated pulses q_o having a repetition rate equal to approximately twice the frequency of the test voltage.

This will enable the instrument to be used for the measurement of partial discharge magnitude during an actual test near the inception voltage where the number of pulses per cycle is small. The partial discharge magnitude under these conditions is then approximately equal to q_o multiplied by the ratio of the instrument reading during the test to that during the calibration. This relationship also applies over a limited range of pulse repetition rates where the variation of readings due to the factor $f(N)$ is small.

Whenever measurements are performed with a radio interference meter, the records from the test should include the readings obtained in microvolts and the determined equivalent apparent charge in picocoulombs together with relevant information concerning the determination of the scale factor (such as calibration, pulse repetition rate, test voltage frequency, etc.).

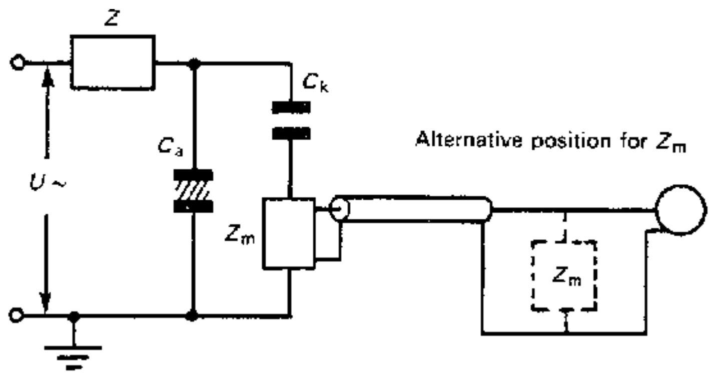

FIG. 1a. — Measuring impedance connected in series with the coupling capacitor.

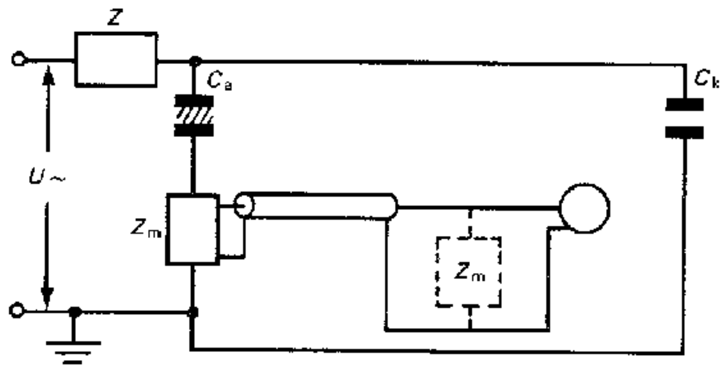

FIG. 1b. — Measuring impedance connected in series with the test object.

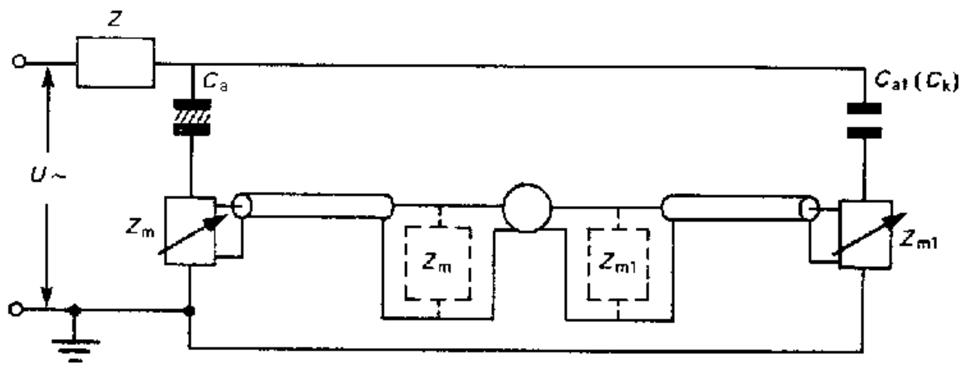

FIG. 1c. — Balanced circuit arrangement.

FIG. 1. — Basic partial discharge test circuits.

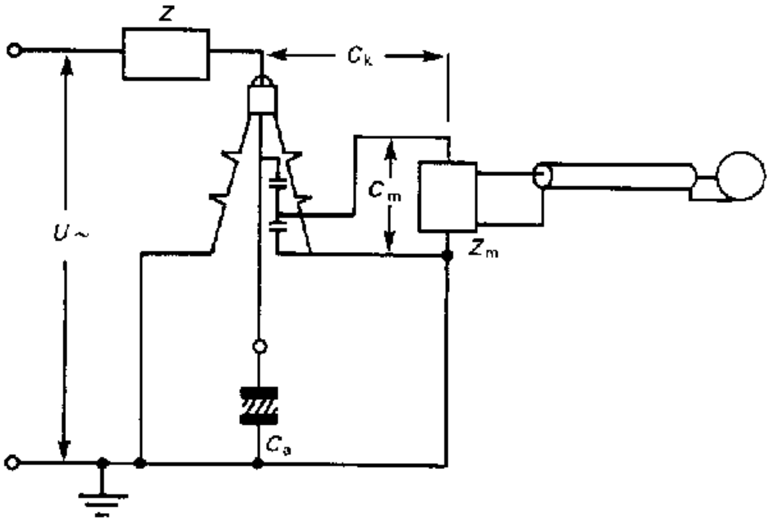

FIG. 2. — Test circuit for measurement at a tapping of a bushing.

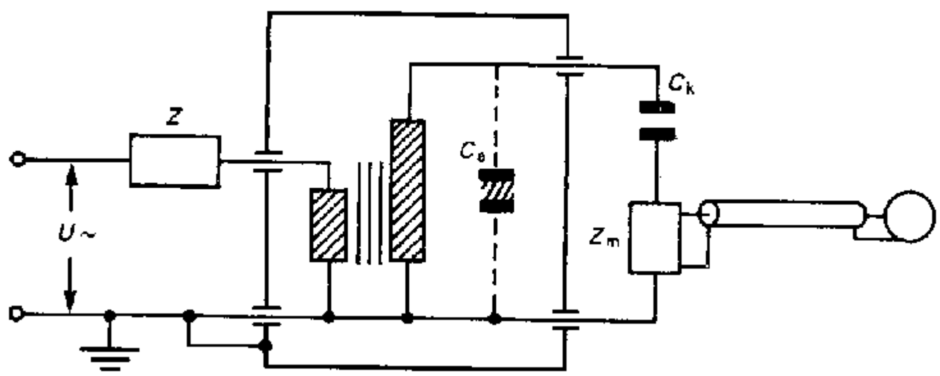

FIG. 3. — Test circuit for measuring self-excited test objects.

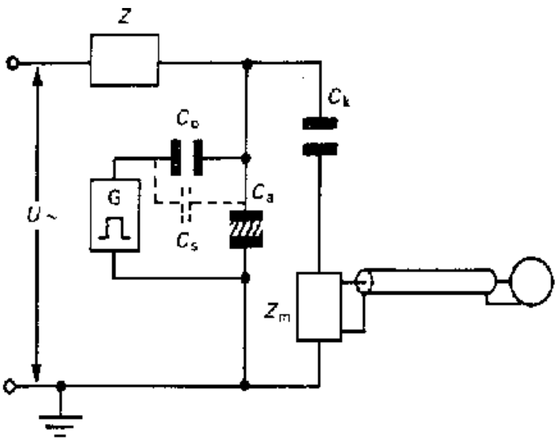

FIGURE 4a

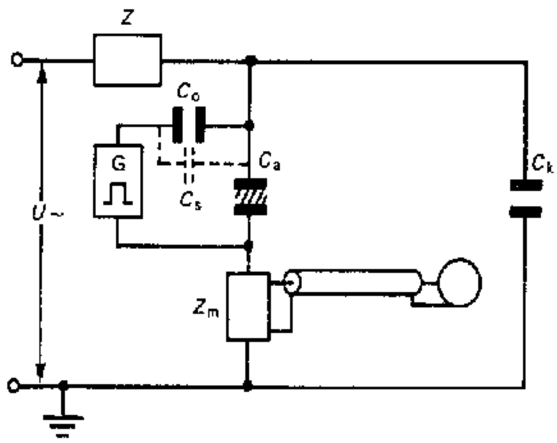

FIGURE 4b

FIG. 4. — Connections for the calibration of the complete test arrangement.

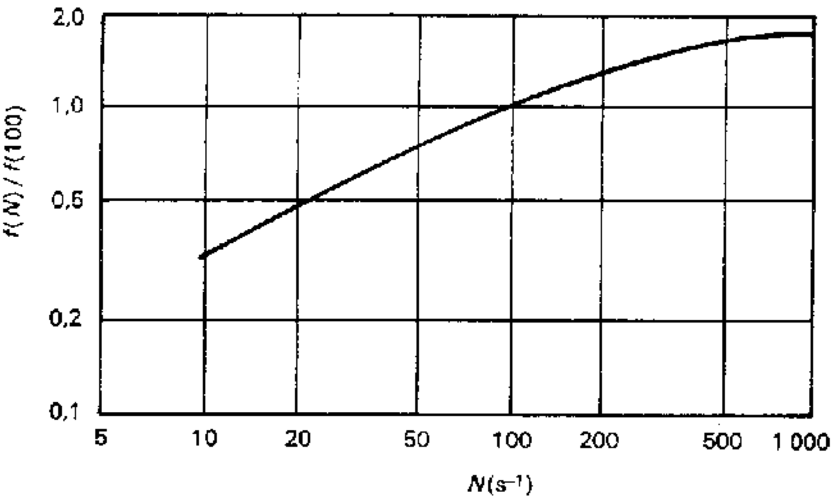

FIG. 5. — Variations of C.I.S.P.R. radio interference meter reading *f*(*N*) with repetition rate *N*, for constant pulses.

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