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Merjenje nizkofrekvenčnih elektromagnetnih polj z vidika izpostavljenosti ljudi – Posebne zahteve za instrumente in napotki za merjenje

Measurement of low-frequency magnetic and electric fields with regard to exposure of human beings – Special requirements for instruments and guidance for measurements

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Measurement of low-frequency magnetic and electric fields with regard to exposure of human beings – Special requirements for instruments and guidance for measurements

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

MEASUREMENT OF LOW-FREQUENCY MAGNETIC AND ELECTRIC FIELDS WITH REGARD TO EXPOSURE OF HUMAN BEINGS – SPECIAL REQUIREMENTS FOR INSTRUMENTS AND GUIDANCE FOR MEASUREMENTS

FOREWORD

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International Standard IEC 61786 has been prepared by IEC technical committee 85: Measuring equipment for electromagnetic quantities.

The text of this standard is based on the following documents:

FDIS	Report on voting
85/191/FDIS	85/193/RVD

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

Annexes A and B form an integral part of this standard.

Annexes C, D, E, F, G and H are for information only.

Words in **bold** in the text are defined in clause 3.

INTRODUCTION

The increasing interest in characterizing human exposure to quasi-static magnetic and electric fields in a number of environments has led to the development and marketing of many field meters with a range of specifications. Sources of **quasi-static fields** include devices that operate at power frequencies (50/60 Hz) and produce power frequency and power frequency harmonic fields, as well as devices which produce fields that are independent of the power frequency. Examples in the latter category include video display terminals (vertical scan magnetic field), electric railroads ($16^{2/3}$ Hz and 25 Hz), mass transportation systems (0 Hz to 3 kHz depending on characteristics of adjustable speed drive), commercial airplanes (400 Hz), induction heaters (50 Hz to 9 kHz), and electric automobiles. Because of differences in the characteristics of the fields from sources in the various environments, e.g. frequency content, temporal and spatial variations, polarization, and magnitude, the instrumentation requirements and measurement procedures will be different in the various environments. Commercially available instrumentation exists to measure human exposure to the field levels as well as to other parameters that characterize the fields. The instrumentation and measurement methods, as they may pertain to human exposure, are the focus of this document. It should be noted that the parameters that describe **quasi-static fields** and the mechanisms for their interaction with humans during magnetic and electric field exposure are still unknown.

The intended users of this International Standard include manufacturers of instrumentation and groups or individuals interested in characterizing quasi-static magnetic and electric fields as they relate to human exposure. It is assumed that users intending to perform measurements have some knowledge of the instrumentation as well as field sources and their characteristics. In the absence of such knowledge, it is strongly advised that some training be received. This standard may serve as a textbook for the training process because of the technical information provided in the annexes.

MEASUREMENT OF LOW-FREQUENCY MAGNETIC AND ELECTRIC FIELDS WITH REGARD TO EXPOSURE OF HUMAN BEINGS – SPECIAL REQUIREMENTS FOR INSTRUMENTS AND GUIDANCE FOR MEASUREMENTS

1 Scope

This International Standard provides guidance for measuring the steady-state root-mean-square (r.m.s.) values of quasi-static magnetic and electric fields which have a frequency content in the range 15 Hz to 9 kHz. Sources of **quasi-static fields** include devices that operate at power frequencies and produce power frequency and power frequency harmonic fields, as well as devices that produce fields independent of the power frequency. The magnitude ranges covered by this standard are 100 nT to 100 mT and 1 V/m to 50 kV/m for magnetic fields and electric fields, respectively. When measurements outside this range are performed, most of the provisions of this standard will still apply, but certain provisions such as specified uncertainty and calibration procedure may need modification. Specifically, this standard

- defines terminology;
- identifies requisite field meter specifications;
- indicates methods of calibration;
- defines requirements on instrumentation uncertainty;
- describes general characteristics of fields;
- surveys operational principles of instrumentation;
- describes measurement methods that achieve defined goals pertaining to human exposure.

Sources of uncertainty during calibration and measurements are also identified and guidance is provided on how they should be combined to determine total **measurement uncertainty**. In regard to electric field measurements, this standard considers only the measurement of the unperturbed electric field strength at a point in space (i.e. the electric field prior to the introduction of the field meter and operator) or on conducting surfaces.

NOTE – Some separation between the normative measurement requirements in clauses 5 and 6 and the example measurement protocols and guidance for measurements in annexes D and E is unavoidable because of format requirements.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All normative documents are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 61000-3-2:1995, *Electromagnetic compatibility (EMC) – Part 3: Limits – Section 2: Limits for harmonic current emissions (equipment input current ≤16 A per phase)*

IEC 61000-4-2:1995, *Electromagnetic compatibility (EMC) – Part 4: Testing and measurement techniques – Section 2: Electrostatic discharge immunity test* – Basic EMC Publication

IEC 61000-4-3:1995, *Electromagnetic compatibility (EMC) – Part 4: Testing and measurement techniques – Section 3: Radiated, radio-frequency, electromagnetic field immunity test*

IEC 61000-4-4:1995, *Electromagnetic compatibility (EMC) – Part 4: Testing and measurement techniques – Section 4: Electrical fast transient/burst immunity test – Basic EMC publication*

IEC 61000-4-6:1996, *Electromagnetic compatibility (EMC) – Part 4: Testing and measurement techniques – Section 6: Immunity to conducted disturbances, induced by radio-frequency fields*

IEC 61000-4-8:1993, *Electromagnetic compatibility (EMC) – Part 4: Testing and measurement techniques – Section 8: Power frequency magnetic field immunity test* – Basic EMC Publication

CISPR 11:1990, *Limits and methods of measurement of electromagnetic disturbance characteristics of industrial, scientific and medical (ISM) radio-frequency equipment*

ISBN 92-67-01075-1:1993, *International vocabulary of basic and general terms in metrology*, International Organization for Standardization.

ISBN 92-67-10188-9:1995, ISO TAG, ISO Technical Advisory Group on Metrology, Working Group 3, *Guide to the expression of uncertainty in measurement.*

IEEE Std 539:1990, *IEEE Standard Definitions of Terms Relating to Corona and Field Effects of Overhead Power Lines*.

3 Definitions

For the purposes of this International Standard, the following definitions apply.

NOTE – Throughout this standard, the words "magnetic flux density" and "magnetic field" will be considered synonymous.

3.1 Tests

3.1.1
acceptance tests
contractual test to prove to the customer that the device meets certain conditions of its specifications

3.1.2
type test
test of one or more devices made to a certain design to show that the design meets certain specifications

NOTE – This test is normally performed by the designer/manufacturer of the device.

3.2 Meters

3.2.1
alternating electric field strength meter

meter designed to measure alternating electric fields. Three types of electric field strength meters are available: **free-body meter**, **ground reference meter**, **electro-optic meter.**

NOTE – Electric field meters consist of two parts: the probe or field-sensing element, and the detector which processes the signal from the probe and indicates the r.m.s. value of the electric field with an analogue or digital display.

3.2.2
electro-optic meter

meter that measures the electric field strength by changes in the transmission of light through a fibre or crystal which are due to the influence of the electric field

NOTE – While there are several electro-optic methods that can be used for measuring electric fields, e.g. the Pockels effect, the Kerr effect, and interferometric techniques, this standard only considers electro-optic field meters that utilize the Pockels effect.

3.2.3
free-body meter

meter that measures the electric field strength at a point above the ground and is supported in space without conductive contact to earth

NOTE – **Free-body meters** are commonly constructed to measure the induced current between two isolated parts of a conductive body. Since the induced current is proportional to the time derivative of the electric field strength, the meter's detector circuit often contains an integrating stage in order to recover the waveform of the electric field. The integrated current waveform also coincides with that of the induced charge. The integrating stage is also desirable, particularly for the measurement of electric fields with harmonic content, because this stage (i.e. its integrating property) eliminates the excessive weighting of the harmonic components in the induced current signal.

3.2.4
fluxgate magnetometer

instrument designed to measure magnetic fields by making use of the non-linear magnetic characteristics of a probe or sensing element that has a ferromagnetic core

3.2.5
ground reference meter

meter that measures the electric field at or close to the surface of the ground, frequently implemented by measuring the induced current or charge oscillating between an isolated electrode and ground. The isolated electrode is usually a plate located level with or slightly above the ground surface.

NOTE – **Ground reference meters** measuring the induced current often contain an integrator circuit to compensate for the derivative relationship between the induced current and the electric field.

3.2.6
magnetic flux density meter

meter designed to measure the magnetic flux density

NOTE 1 – Magnetic field meters consist of two parts: the probe or field-sensing element, and the detector which processes the signal from the probe and indicates the r.m.s. value of the magnetic field with an analogue or digital display.

NOTE 2 – Several types of meters are in common use, e.g. field meters with **coil probes**, meters with **Hall-effect probes**, and meters that combine two coils with a ferromagnetic core as in a **fluxgate magnetometer**.

3.2.7
survey meter

lightweight battery-operated meter that gives a real time read-out and that can be held conveniently by hand in order to conduct survey type measurements in different locations

3.2.8

coil probe

magnetic flux density sensor comprised of a coil of wire that produces an induced voltage proportional to the time derivative of the magnetic field

NOTE 1 – Since the induced voltage is proportional to the time derivative of the magnetic flux density, the detector circuit of the sensor requires an integrating stage to recover the waveform of the magnetic flux density.

NOTE 2 – This probe can also be used to measure static (d.c.) magnetic flux density if the probe is rotated.

3.2.9

Hall effect probe

magnetic flux density sensor containing an element exhibiting the Hall effect to produce a voltage proportional to the magnetic flux density

NOTE – **Hall effect probes** respond to static as well as time-varying magnetic flux densities. Due to limited sensitivity and saturation problems sometimes encountered when attempting to measure small power frequency flux densities in the presence of the substantial static geomagnetic flux of the earth, **Hall-effect probes** have seldom been used to measure magnetic fields of a.c. power lines.

3.3 Meter characteristics

3.3.1

crest factor

for periodic functions, the ratio of the waveform crest (peak, maximum) value to its r.m.s. value

3.3.2

crosstalk

noise or extraneous signal caused by a.c. or pulse-type signals in adjacent circuits

3.3.3

frequency response

response (reading) of a field meter to a field of constant amplitude but different frequencies

3.3.4

pass-band

(1) (data transmission) a range of frequency spectra which can pass at low attenuation

(2) (circuits and systems) a band of frequencies that pass through a filter with little attenuation (relative to other frequency bands such as a stop-band)

3.3.5

rectified average (calibrated in r.m.s.) detector (see 3.3.6)

detector circuit that rectifies the signal from the probe and is calibrated to give the correct r.m.s. value of a sinusoidal field at a given frequency

NOTE – If there are harmonics in the field, a field meter with a **rectified average (r.m.s.) detector** will not indicate the true r.m.s. value of the field if the signal from the probe is proportional to the time derivative of the field. If the detector contains a stage of integration, the error is reduced. The error will also be a function of the phase relation between the harmonic and fundamental field components [36], [61].

3.3.6

true r.m.s. detector (see rectified average (calibrated in r.m.s.) detector)

detector that contains a circuit component that performs the mathematical operation

$$\sqrt{\frac{1}{T}\int_{0}^{T}[v(t)]^{2}\mathrm{d}t} \qquad (1)$$

to a periodic signal *v(t)*, where *T* is the period of the signal.

NOTE 1 – If *v(t)* is proportional to the time-derivative of the field, the detector circuit also requires a stage of integration prior to the r.m.s. operation in order to recover the waveform of the magnetic flux density [25], [61]. This type of detector gives the true r.m.s. value of a field containing harmonics provided that the **frequency response** of the detector is flat over the frequency range of interest.

NOTE 2 – If significant levels of harmonics are present in *v(t)*, particular attention should be given to the possibility of amplifier saturation effects if the integration follows one or more stages of amplification.

3.4 Field characteristics

3.4.1

maximum r.m.s. value of electric field (maximum electric field)

measurement of elliptically polarized quasi-static electric and magnetic fields. At a given point, the root-mean-square (r.m.s.) value of the semi-major axis of the electric field ellipse

3.4.2

maximum r.m.s. value of magnetic field (maximum magnetic field)

measurement of power frequency electric and magnetic fields. At a given point, the root-mean-square (r.m.s.) value of the semi-major axis of the magnetic field ellipse

3.4.3

perturbed field

field that is changed in magnitude or direction, or both, by the introduction of an object

NOTE – The electric field at the surface of the object is, in general, strongly perturbed by the presence of the object. At power frequencies, the magnetic flux density is not, in general, greatly perturbed by the presence of objects that are free of magnetic materials. Exceptions to this include regions near the surface of thick electrical conductors and regions far from thick conductors, if the conductor is close to the magnetic field source. The perturbation in these instances is due to opposing magnetic fields produced by eddy currents in the conductors.

3.4.4

unperturbed field

field at a point that would exist in the absence of persons or movable objects

3.4.5

quasi-static field

field that satisfies the condition $f << c \div l$, where f is the frequency of the field, c is the speed of light, and l is a characteristic dimension of the measurement geometry, e.g. the distance between the field source and the measurement point

NOTE – Power frequency magnetic and electric fields near power lines and appliances are examples of **quasi-static fields**.

3.4.6

resultant electric field

electric field given by the expression

$$E_{\mathrm{R}} = \sqrt{E_x^2 + E_y^2 + E_z^2} \qquad (2)$$

where E_x, E_y, and E_z are the r.m.s. values of the three orthogonal field components

The **resultant electric field** is also given by the expression

$$E_R = \sqrt{E_{max}^2 + E_{min}^2} \tag{3}$$

where E_{max} and E_{min} are the r.m.s. values of the semi-major and semi-minor axes of the electric field ellipse, respectively. The resultant E_R is always $\geq E_{max}$. If the electric field is linearly polarized, $E_{min} = 0$ and $E_R = E_{max}$. If the electric field is circularly polarized, $E_{max} = E_{min}$ and $E_R \approx 1{,}41\ E_{max}$.

NOTE – The definition of "effective field strength" in CENELEC prestandard ENV 50166-1 [5] is equivalent to the **resultant magnetic field** or **resultant electric field**, as the case may be.

3.4.7
resultant magnetic field

magnetic field given by the expression

$$B_R = \sqrt{B_x^2 + B_y^2 + B_z^2} \tag{4}$$

where B_x, B_y, and B_z are the r.m.s. values of the three orthogonal field components

The **resultant magnetic field** is also given by the expression

$$B_R = \sqrt{B_{max}^2 + B_{min}^2} \tag{5}$$

where B_{max} and B_{min} are the r.m.s. values of the semi-major and semi-minor axes of the magnetic field ellipse, respectively. The resultant B_R is always $\geq B_{max}$. If the magnetic field is linearly polarized, $B_{min} = 0$ and $B_R = B_{max}$. If the magnetic field is circularly polarized, $B_{max} = B_{min}$ and $B_R \approx 1{,}41\ B_{max}$.

NOTE – The definition of "effective field strength" in CENELEC prestandard ENV 50166-1 [5] is equivalent to the **resultant magnetic field** or **resultant electric field**, as the case may be.

3.5 Measurements

3.5.1
correction factor

numerical factor by which the uncorrected result of a measurement is multiplied to compensate for a known error

NOTE – Since the known error cannot be determined perfectly, the compensation cannot be complete.

3.5.2
coverage factor

numerical factor used as a multiplier of the combined **standard uncertainty** in order to obtain an expanded uncertainty

NOTE – For a quantity z described by a normal distribution with expectation μ_z and standard deviation σ, the interval $\mu_z \pm k\sigma$ encompasses 68,27, 95,45, and 99,73 percent of the distribution for a **coverage factor** $k = 1, 2,$ and 3, respectively.

3.5.3
scale factor

factor by which the instrument reading is multiplied to obtain its input quantity

3.5.4

spot measurement (point-in-time measurement)

measurement that is performed at some instant and point in space, that does not provide information regarding temporal or spatial variations of the field

3.5.5

standard uncertainty

uncertainty of the result of a measurement expressed as a standard deviation

3.5.6

uncertainty of measurement

parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand

NOTE – **Uncertainty of measurement** generally comprises many components. Some of these components may be estimated on the basis of the statistical distribution of the results of series of measurements, and can be characterized by experimental standard deviations. Estimates of other components can be based on experience or other information.

4 Symbols

a = radius of **coil probe**; radius of spherical electric field probe

$2a$, $2b$ = side dimensions of rectangular coil

B = magnetic flux density vector

B_f = magnetic flux density (fundamental frequency)

B_j = magnetic flux density at jth frequency (j = 1 for fundamental frequency)

$B_{\mathrm{RL}j}$ = CENELEC magnetic flux density reference level at jth frequency

B_0 = amplitude of alternating magnetic field

B_R = **resultant magnetic field**

B_z = axial magnetic flux density

$B_{x,y,z}$ = r.m.s. values of orthogonal components of magnetic flux density

B_max, B_min = r.m.s. values of semi-major and semi-minor axes of magnetic field ellipse

C = stray capacitance of **coil probe**

c_e = electro-optic coefficient of Pockels crystal

d = spacing of parallel plates; distance from electromagnetic field source

D = electric displacement vector

E = electric field strength

E_i = electric field at ith frequency (i = 1 for fundamental frequency)

$E_{\mathrm{RL}i}$ = CENELEC electric field reference level at ith frequency

E_R = **resultant electric field**

E_0 = uniform electric field strength

E' = electric field in Pockels crystal

$E_{x,y,z}$ = r.m.s. values of orthogonal components of electric field

E_max, E_min = r.m.s. values of semi-major and semi-minor axes of electric field ellipse

I = current to magnetic field coils

I_i = incident light (electro-optic field meter)

I_t = transmitted light (electro-optic field meter)

l = Pockels crystal thickness

L = inductance of **coil probe**

n = index of refraction

N = number of turns of wire (magnetic field coil system)

Q = induced charge

r = distance between magnetic field source and measurement location; resistance of **coil probe** and leads

R = approximate input impedance of detector circuit (magnetic field meter)

S = electrode surface area (electric field meter)

t = time

T = period of periodic signal

V = voltage

$v(t)$ = periodic electrical signal

v_p = **coil probe** voltage

W = ratio of **coil probe** voltage to induced voltage

Z = impedance in current injection circuit

α_i = fraction of *i*th harmonic in magnetic field

ΔB_{max1} = largest difference in percentage between magnetic field at centre of single-axis probe and average field (across area of probe) at maximum reading in dipole magnetic field

ΔB_{max3} = largest difference in percentage between average **resultant magnetic field** and magnetic field at centre of three-axis probe in dipole magnetic field

ε_0 = permittivity of free space

λ = wavelength of light

μ_0 = permeability of free space

ϕ = magnetic flux

ω = angular frequency of alternating field

5 Measurement of alternating magnetic fields

5.1 Instrumentation specifications

The various types of instrumentation available for characterizing quasi-static magnetic fields are described in D.1. Sufficient information shall be provided with the instrumentation, including instrument specifications and a clearly written instruction manual, to enable users to determine compliance with this standard, to aid them in the proper operation of the field meter, and to assess the usefulness of the device for the user's application. Complicated operating procedures should be avoided. The instrument specifications that should be provided and/or satisfied are given below.

NOTE – Instruments not complying with the specifications below may be used if it can be demonstrated that, under the conditions the instrument is used, the results obtained will not differ significantly from those obtained with a meter which is in compliance with this standard. For example, a meter with a **rectified average detector** with or without an integrating stage may be used if it can be shown that the harmonics in the field are negligible, and if the instrument has been calibrated for the fundamental frequency in the field.

5.1.1 Instrumental uncertainty

The measuring system for alternating magnetic fields should indicate the r.m.s. value of uniform magnetic fields with an uncertainty of less than ±(10 % of reading +20 nT) after **correction factors** have been applied, if appropriate.

NOTE 1 – The uncertainty of the instrument is determined from several components such as the calibration uncertainty, temperature drift of the electronics, stability and external noise sources. The above uncertainty is associated with the design and functioning of the **magnetic flux density meter** in a nearly uniform field. The 10 % element refers to the uncertainty during calibration over the frequency range (**pass-band**) specified for the instrument and includes uncertainties in the value of the magnetic flux density and additional uncertainties during the calibration process (see 5.2.2). The **coverage factor** is 2. The inclusion of 20 nT anticipates instrumental uncertainties during the calibration of the most sensitive scales and when fields in the order of 0,1 µT are measured.

NOTE 2 – Other sources of **measurement uncertainty** and guidelines on the treatment of uncertainties are given in clause B.1 and 5.3, respectively.

5.1.2 Magnitude range

The magnitude range over which the instrument operates within the specified uncertainty shall be clearly indicated.

5.1.3 Pass-band

The instrument shall be provided with calibration data or specifications that enable the user to assess the uncertainty in determining field levels when using the instrument in fields containing different frequencies. This information should also include the sensitivity of the instrument to frequencies beyond the intended useful range, e.g. the –3 dB points. The **frequency response** of the instrument shall be such that the requirement of the instrumental uncertainty (see 5.1.1) is fulfilled over the frequency range for which it is intended.

NOTE – The permitted instrumental uncertainty associated with the **frequency response** is increased to ±20 % (**coverage factor** 2) for small personal **exposure meters**, devices that can be worn, and which periodically record the power frequency and power frequency harmonic **resultant magnetic field** (see clause D.1).

5.1.4 Operating temperature and humidity ranges

The temperature and relative humidity ranges over which the instrument operates within the specified uncertainty should be no less than 0 °C to 45 °C and 5 % to 95 %, respectively. Sudden temperature changes that can lead to condensation in the instrument should be avoided (see clause B.1).

5.1.5 Power supplies

If batteries are used, provision should be made to indicate whether the battery condition is adequate for proper operation of the field meter. Instruments used to record personal exposure should be capable of at least 8 h operation within their rated uncertainty before replacement or recharging of the batteries becomes necessary. If rechargeable batteries are used, it is recommended that the instrumentation is not operated while connected to the mains voltage.