Uncertainties in assessment of worker exposure of low frequency electric and magnetic fields

Yngve Hamnerius

Signals & Systems, Chalmers University of Technology
SE-41296 Goteborg, Sweden

yngve.hamnerius@chalmers.se

Introduction. Exposure of the human body to time varying electric and magnetic fields may potentially cause health problems The International Commission on Non-Ionizing Radiation Protection (ICNIRP) has set international guidelines for limiting the exposure ICNIRP (1998). Based on these guidelines the European Union released the "Directive 2004/40/EC of the European Parliament and of the Council of 29 April 2004 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields)".

Most European member states already have some regulations for radiofrequency field but usually not for low frequency fields. In this paper the focus is on the demands on low frequency electric and magnetic fields. Exposure to time varying electric and magnetic fields result in induction of internal body current, and the known adverse effects are associated with nerve excitation. ICNIRP's basic restriction therefore limits the induced current density in CNS. In the frequency range 4 Hz – 1 kHz, the limit is set at 10 mA/m^2 (rms, averaged over a cross-section of 1 cm^2 perpendicular to the current direction) for occupational exposure, a value not to be exceeded at any time. From this basic restriction, reference levels (RL) have been calculated assuming a worst case scenario. For pure 50 Hz sinusoidal electric fields the RL is 10 kV/m and for magnetic fields the RL is 500 µT. However, if it can be shown that the basic restriction is not exceeded, although the exposure level exceeds the RL, continued exposure is allowed.

In order to show compliance with the directive the worker exposure must be assessed. An assessment could include measurements or calculations of the electric and/or magnetic field strength. If it can be shown that the reference levels are not violated this could fulfill the requirements in the directive. However there is always a measurement uncertainty that has to be taken in account when assessing if the limits are violated.

If the reference levels are exceeded an assessment of the induced current density in the CNS can show if the basic restrictions are in compliance with the directive. This can not be measured, but there exists methods to calculate induced current. These calculations can be done analytically in simplified homogenous body models or numerically in more realistic anatomical models. The uncertainty in these calculations has to be estimated.

For an assessment value of *X*, a determined assessment uncertainty of *U* and a limit value of *L*, the uncertainty can be assessed against the limit as follows:

To show that the actual value is below the limit value:

$X + U \leq L$

To show that the actual value is above the limit value:

$X - U > L$

If neither of the above conditions is fulfilled then the result of the comparison is uncertain.

Uncertainties in measurements of electric fields. There are many sources of uncertainties in measurements of low frequency electric fields. One major problem is that the measurement instrument will influence the field distribution. In principle all measurement instruments will effect the electric field if the instrument is not in line with an object with similar dielectric properties. An example of where the disturbance of the field pattern could be negligible is measurements of the electric field strength at ground level under a power line with a disk shaped electric field meter which is dug into the ground so that the sensor surface is in line with the ground. We have performed tests where an EnviroMentor EMM-4 instrument has been dug into the ground and compared the result with the case when the instrument is placed on the ground. In the latter case the sensor surface is approximately 10 cm above the ground level and an increase in the measured field strength of about 30 % was registered due to the influence of the instrument. Not only the instrument but also the person performing the measurement could seriously influence the field distribution. Therefore some kind of remote readout is needed to perform measurements of the electric field. Most low frequency electric field meters are not isotropic but usually measure the field which impinges into the instrument sensor surface. The instruments could be designed to be used grounded or free floating relative ground.

The ICNIRP guidelines says "The reference levels are intended to be spatially averaged values over the entire body of the exposed individual, but with the important proviso that the basic restrictions on localized exposure are not exceeded" It is more or less impossible to make a correct assessment of the electric field strength over the entire body with most of today's instrument.

The electric field strength is also affected by the environment; especially changes in the humidity could change the field distribution. These problems are not the only sources to uncertainties, but of course instrument errors, complex wave forms, position uncertainties, variations in the field source, variations in posture etc contributes to the total measurement uncertainty.

Work in high electric field strength, in for example 400 kV substations, often involves exposures up to 15 kV/m, while the magnetic fields were well below the RL. ICNIRP states "For the specific case of occupational exposures at frequencies up to 100 kHz, the derived electric fields can be increased by a factor of 2 under conditions in which adverse indirect effects from contact with electrically charged conductors can be excluded." ICNIRP has a RL for contact currents which for the frequency range 0 – 2500 Hz is 1 mA. This means that the electric field RL at 50 Hz can be increased to 20 kV/m if the contact currents are less than 1 mA.

The work in a substation involves touching of control units of circuit breakers and disconnectors as well as other grounded metallic objects exposed to high electrical fields. Our measurements (Cedergren 2006, Hamnerius 2006) have show that most work in a 400 kV substation gives rise to steady state contact currents of less than 0.2 mA. However when simultaneously touching a grounded object and an ungrounded metallic object such as a vehicle, contact currents above 1 mA were measured.

Uncertainties in measurements of magnetic fields. Low frequency magnetic fields are generally more easy to measure as the instrument and the person performing the measurements have a negligible influence on the field distribution. Many magnetic field instruments are more or less isotropic which also simplifies the measurements. One source to uncertainty is the size and shape of the measurement elements, usually coils, which means that the magnetic field is not measured in a single point but in some way averaged over the sensor surface. Other sources to uncertainty are:

- the actual position of the probe in relation to the planned measurement point;
- calibration or stated accuracy of the measurement instrument;
- interaction between the equipment under evaluation and the measurement system;
- repeatability;
- effect of the environment during the measurement;
- complex, non-repeatable waveforms.

For non sinusoidal fields some kind of frequency analysis has to be done, this can be done with spectrum analysers, FFT or time domain measurements with weighting filters. This analysis adds to the total uncertainty. ICNIRP requires that the different frequency components shall be compared with the limiting values and that these quotients shall be summed. If the phase of the different frequency components are not considered this will result in an overestimation. Frequency analysis of non repeatable pulses or single pulses will also add to the uncertainty as a FFT calculation will give rise to false frequency components if no filtering is applied.

Uncertainties in analytical and numerical modeling. Analytical modeling can only be used to calculate the fields and induced current density in special, often simplified, cases. Calculations of induced current densities can only be made in simple geometries such as spheroids. The dielectric properties of different organs can not be modelled, usually homogenous dielectric properties are used which leads to substantial uncertainties.

More realistic anatomical models are used in numerical modelling. One problem is that just a few models and postures exist, mainly of adult men. Therefore uncertainties in the result due to difference in the anatomical model size, weight and posture compared to the assessed situation. Also uncertainty in the values of tissue electrical properties will contribute to the total uncertainty. Due to limitations in the models and computer capacity, calculations are made with voxel size and shape which can not model the fine anatomical details. Another source to uncertainties is the calculation method where problems with stair casing and convergence could lead to substantial errors, especially at the single voxel level. It is not only the accuracy of the anatomical model that affects the uncertainty, the modelled parameters of the source equipment is equally important.

ICNIRP states that the current density in the CNS shall be averaged over a cross-section of 1 cm^2 perpendicular to the current direction. This averaging gives rise to uncertainties in the voxel model.

Discussion. Due to the above mentioned measurement and calculation problems the total uncertainty is usually quite substantial for these assessments. In a draft European basic standard for the evaluation of human exposure to electromagnetic fields from equipment for arc welding and allied processes (prEn 50444) it is stated that a reasonable expanded assessment uncertainties for measurements of magnetic fields for frequencies below 10 kHz is +58 %, -37 % (± 4 dB) and for the frequency band 10 kHz - 1 MHz is +41 %, -30 % (± 3 dB). For modelling a reasonable uncertainty of ± 50 % is stated for the frequency interval up to 1 MHz.

The total uncertainty in measurements and modelling must therefore be taken in account when assessing compliance with the ICNIRP guidelines.

References.

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