19 EXAMINING EMF EXPOSURE IN LOW-FREQUENCY FIELDS - TIME OR FREQUENCY ANALYSIS?

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Summary

The publication Berufsgenossenschaftliche Vorschrift "Elektromagnetische Felder" establishes reference levels and evaluation procedures for a variety of fields in order to limit EMF exposure. It includes two equations for multiple low-frequency fields. The central statements contained in it are explained in detail in the following. The subsequent discussion of different measurement solutions refers to them extensively. In addition to broadband field strength meters and FFT analyzers, the innovative "Shaped Time Domain" (STD) method is presented as a universal solution for examining fields of all kinds.

1 Classification of procedures according to Berufsgenossenschaftliche Vorschrift "Elektromagnetishe Felder"

The issue of Berufsgenossenschaftliche Vorschrift "Elektromagnetische Felder" (also referred to as BGV 13) represents a good opportunity to clarify some of the requirements described in this specification and examine how they can be applied to test equipment. This paper is based on the December 1998 version of BGV 13 drafted by the Technical Committee and is concerned solely with low-frequency fields up to 29 kHz. It does not take account of any other standards dealing with electromagnetic fields because they cover different aspects.

Three different procedure classes are mentioned, corresponding to those described in VDE 0848 Parts 1 and 2 (standard in preparation). These are stationary, sinusoidal fields ("fields with one frequency"), stationary, multiple-frequency fields ("fields with more than one frequency") and "pulsed fields". A recommended procedure is specified for each class for estimating the exposure from these field types (see table). In the first instance, the estimation is based on the field-strength reference levels, which are given as root-mean-square values and listed in a table as a function of frequency. Multiple-frequency fields are estimated with the aid of an equation; how this equation should be interpreted is explained in more detail below. There are a few typical waveforms (in the time domain) for the pulsed-signal class. A series of equations is provided for estimating exposure from this type of field.

Table: Classification of procedures

Type of field	Estimation procedure
• Single-frequency fields	• Derived reference levels (Sections 1.2.1.1/ .2)

• Multiple-frequency fields • Pulsed fields	• Equations (Section 1.2.1.3) • Field-strength change over time (Section 1.3.1)

2 Equations / multiple-frequency fields

Whereas measuring and evaluating stationary fields with a single frequency is not normally problematic, multiple-frequency fields are much more difficult to estimate correctly. All fields estimated using this method must fulfil two basic requirements. They must:

- be stationary, i.e. they must exist for the full duration of the measurement without changing, and
- have frequency components that can be determined sufficiently accurately.

BGV 13 includes two new criteria for estimating the field strength which must be considered simultaneously. The implications of this are described in the following.

2.1 Estimation based on power (root-mean-square value)

Equation (1) takes the power of the analyzed field into account for the first time as an estimation criterion in the low-frequency range (1 Hz…29 kHz).

$$\sum_{k=1}^{n}\left(\frac{B_k}{B_{a,k}}\right)^2 \leq 1 \qquad \text{Equation (1)}$$

The quotients are calculated by referring the r.m.s. values of the spectral components contained in the signal to the reference levels assigned to their frequencies. These values are then summated quadratically to obtain a normalized total power for the field.

2.2 Estimation based on peak value

A stimulus effect that is relevant in connection with exposure in the low-frequency range can be attributed directly to the field peak value considered by equation (2).

$$\sum_{k=1}^{n} \frac{B_k}{B_{a,k}} \leq V_{\max} = 8$$ Equation (2)

The linear summation according to equation (2) results in a peak value that is already normalized to the reference levels. The reference variable V_{max}, which has been fixed at a value significantly different from one, is a notable feature of this equation. It ensures that the value estimated for the peak value component receives a lower weighting than that calculated for the power component (equation (1)).

2.3 The 30% rule

The linear summation according to equation (2) has an inherent drawback: it takes no account of their phase relations, so that the result is only ever approximate, with a tendency to overestimate the peak value. Quotients with an absolute value which is equivalent to less than 30% of the maximum actual value are ignored for evaluation purposes, in order to compensate this tendency to a certain extent.

$$\frac{B_{a,\max}}{B_{a,k}} \cdot \frac{B_k}{B_{\max}} \geq 0,3$$ Equation (3)

According to equation (3), the relevance of the individual quotients is determined by taking the influence of frequency on the reference levels into account ("frequency response shaping"). This weighted view represents another difference between BGV 13 and all previously published standards.
Since lower reference levels are normally defined for higher frequencies, equation (3) gives a higher weighting to quotients with a higher frequency (e.g. harmonics). These may have a very important effect on exposure in terms of personal protection.

Applying the 30% rule can however sometimes lead to strange results, as demonstrated by the example below:
If the field of the analyzed installation has a dominant field component according to equation (3) after the frequency response has been shaped, only this component is taken into account in the value estimated with equation (2). If the operational status of the installation changes subsequently, for instance, the peak value of the spectral line - up to now thought to be dominant - may fall slightly. Consequently, a number of other components, which were not previously required to be considered for the calculation, may now also contribute to the result of equation (2). The fall in the peak value may thus cause the maximum permitted exposure level to be suddenly exceeded.

3 Field strength change over time / pulsed fields

A pulse signal can in principle be represented equally effectively in the time domain ("waveform") and in the frequency domain ("spectrum"). It is not possible to evaluate it using the equations however, since the two prerequisites for doing so (stationary field and adequate frequency resolution) are not fulfilled.
BGV 13 contains a few typical waveforms for this type of field. The equations reproduced there enable the exposure from such fields to be estimated.

4 Alternative measurement methods

Suitable measurement methods and instruments, which are described in the following, are required in order to evaluate the three signal classes mentioned above.

4.1 Broadband / selective field-strength measuring device

This kind of device is ideal for carrying out straightforward, informative measurements in a wide range of practical situations.
If the analyzed field is known to have just one - or only one significant - frequency component (e.g. 50 Hz), a broadband field-strength measuring device is the best alternative. A bandpass and/or reject (notch) filter may be useful for verifying that this spectral component really is the only one that is relevant for evaluation purposes. The measured value is normally displayed as an r.m.s. value and is directly comparable with the reference level.

If multiple-frequency fields need to be analyzed exactly, the relevant quotients for evaluating the equations can be obtained by measuring the various signals (the frequency of which must be already known) selectively. It should be noted that these selective measurements must always be graded and that they are consequently unable to reflect the situation at a given instant in time. The signals recorded using this method may in some cases be consecutive rather than simultaneous. The actual exposure level is therefore not rendered correctly.

4.2 Spectrum analyzer (FFT analyzer)

Multiple-frequency fields can be evaluated much more quickly and easily by means of a spectrum analysis. Field-strength measuring devices based on the spectrum analysis principle are often designed as FFT analyzers. The time characteristic of the analyzed signal which is recorded by the probe is stored temporarily and converted to the frequency domain ("spectrum") using the mathematical procedure known as FFT (Fast Fourier Transformation).

This method allows all the spectral components of the field that occur while the data is being recorded to be analyzed simultaneously. Fields which do not exist simultaneously are recorded separately from one another. Since the measurements are then followed by the calculation ("transformation"), the analyzer may however be temporarily blinded to rapid field changes. This drawback can be overcome in the lower subdomain of the frequency spectrum by using powerful computers ("overlapping real-time mode").

Both fields with a single frequency ("sinusoidal") and stationary, multiple-frequency fields can be measured directly using this method, providing the frequency resolution is adequate. In both cases, it is possible to read off the r.m.s. value or the peak value of each individual frequency component. Harmonic (distortion) analyses are an easy matter.

The field exposure is estimated using the equations explained above. Since account is only taken of those quotients which are equivalent to at least 30% after the frequency response has been shaped, the spectral representation normalized to the respective reference level permits an initial, visual assessment of the situation.
The task of reading off the measured frequency and field strength values can also be simplified by using suitable marker functions.

It is a good idea to perform the calculations directly in the measuring device according to the equations. The result is a dimensionless number, which represents the exposure in relation to the maximum permissible exposure. A value of 100% indicates that the maximum permitted exposure, as defined by the preset reference levels, has been reached.

4.3 Evaluation in the time domain

Various possible methods for measuring "single-frequency fields" and "multiple-frequency fields" have been described above. According to the information contained in BGV 13, a curve of the field strength over time using a transient recorder is a suitable alternative for pulsed fields. It is thus possible to estimate the exposure levels for the typical waveforms.
There are no special procedures for evaluating the strength of other types of field.

5 STD (Shaped Time Domain) measurements

A detailed knowledge of the field, the measurement technique and its constraints are evidently essential in many situations, in order to obtain results that are sufficiently informative to estimate the exposure level. In the frequent instances in which the shape of the signal is unknown, the most suitable measurement and evaluation method needs to be determined by a specially trained person. The results of the evaluation are likely to be false if an inappropriate method is chosen.

If, however, it is possible to forego splitting the analyzed signal into its various frequency components and quantifying their field strengths individually, there is a new method that can be applied to very good effect in the time domain. The influence of frequency on the reference levels can be taken into account by using suitable filters ("frequency response shaping"). Detectors are available for measuring the r.m.s and peak values.

This method is not restricted to certain types of field only. Fields with one or more frequencies can be evaluated just as efficiently as pulsed fields. The principle is ideal for the latter type, because the time-domain reference values specified for the selected pulse fields can be transformed into the frequency-domain reference values contained in the equations. The method is also a suitable alternative for waveforms that deviate from those published in BGV 13. The exposure is calculated in real time for the entire frequency domain.

This measuring device based on this solution enables the actual exposure to be displayed directly as a percentage of the maximum permissible exposure. No special procedures are necessary to apply the method; even relatively unskilled persons can use it to analyze unknown field situations. The aim of BGV 13, namely to allow field strengths to be estimated correctly in the interests of personal protection, can thus be achieved faster and more efficiently.

Note: 0,3 = 0.3 (Formula (3))