Simple assessment of non-sinusoidal, pulsed or intermittent exposure to low frequency electric or magnetic fields at workplaces

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Background

Directive 2013/35/EU of the European Parliament and of the Council of 26 June 2013 establishes minimum health and safety requirements for the protection of workers against the risks arising from exposure to static and time-varying electric, magnetic and electromagnetic fields (EMF). The EMF Directive requires the employers to assess any EMF related risks at the workplace and to take adequate measures to eliminate or to minimize such risks.

Introduction

In the low-frequency (LF) range the physiologically relevant physical quantities for EMF exposure assessment, e.g. electric field strength in the tissue, cannot be easily measured at workplace because they only exist inside the human body. In order to facilitate the determination of the level of exposure at a workplace and the application of the EMF Directive, tables for directly measurable action levels (AL) are given in the Annex of the Directive. If these action levels are not exceeded, an inherent compliance with the given exposure limit values (ELV), also listed in the annex of the EMF Directive, is guaranteed.

Methods

An important issue is the correct assessment of non-sinusoidal, pulsed or intermittent exposures to low frequency electric or magnetic fields at workplaces, for example during the use of resistance welding guns (see figure 1), spot welding or at electrolysis plants.

Figure 1. Worker with resistance welding gun

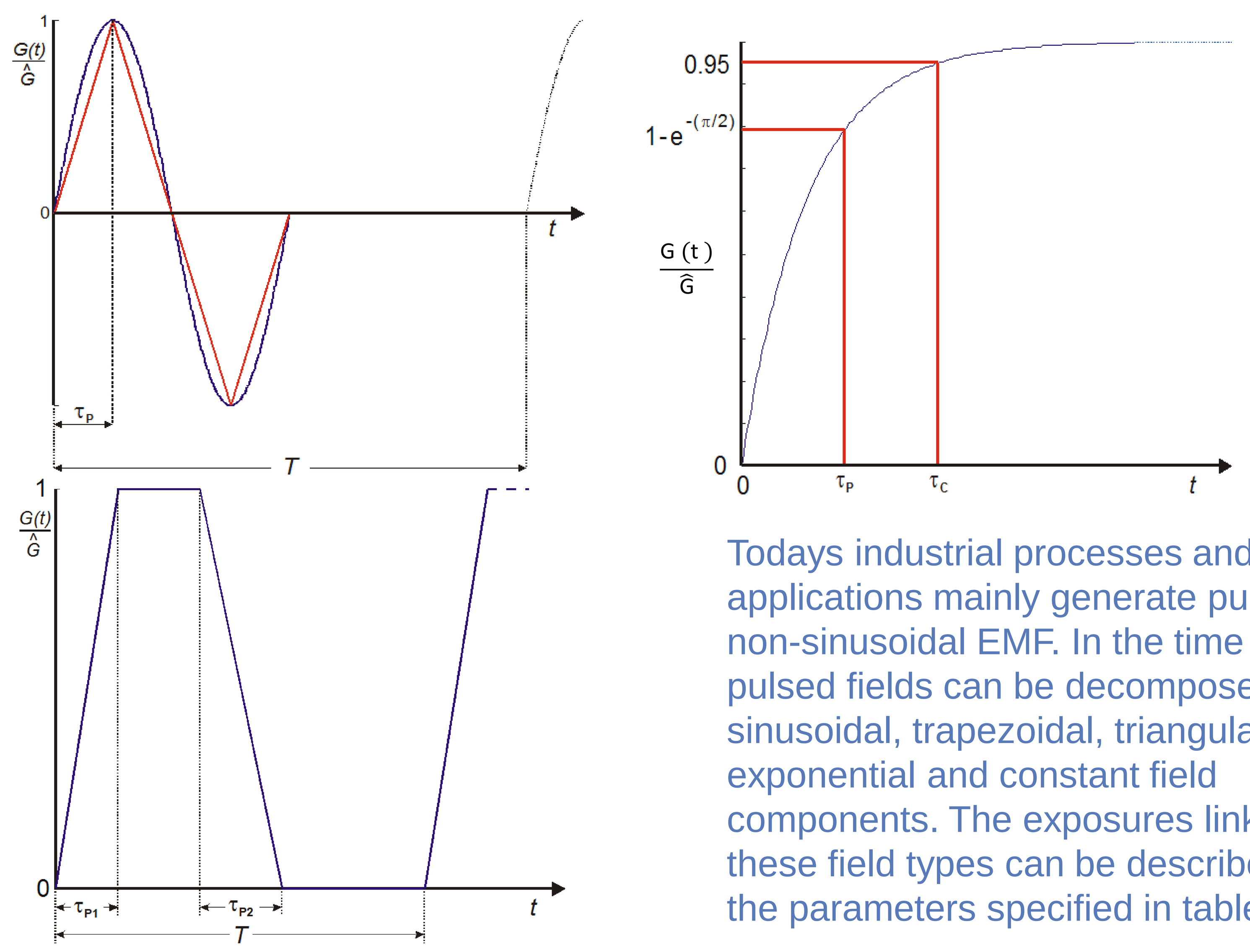
Welding guns are used where stationary equipment or welding robots lack the necessary flexibility or are not cost efficient. Especially in body shops, prototyping, small series production and for special welding requirements manually operated welding guns, which can be easily adapted to the task at hand due to different types and sizes of guns available, are often the only option.

In the low-frequency range up to some 100 kHz the main physiological effect is the electrical stimulation of excitable body tissues like muscles, nerves and sensory organs. The area of interaction with excitable tissue is dependent, among other parameters, on both the direction and the value of the vector of the electric field strength in the tissue. The described procedure is based on laws of physics and physiology, especially on the mechanism of electro-stimulation. The procedure in the time domain provides a simple and safe method to assess non-sinusoidal or pulsed fields [1].

In consideration of the stimulation mechanism follows:

(1) Stimulation effects only occur if the well-defined threshold is exceeded.
(2) Pulses below this threshold cannot create any stimulus even if they are very long.
(3) In case of short pulses intensities need to be higher.

The simple assessment procedure based on physiological effects is included in the Accident Prevention Regulation BGV B11 (DGUV rule 15) of the German Federation of Industrial Accident Insurance Funds [2]. However, this regulation from 2001 does not use the action levels and the exposure limit values of Directive 2013/35/EU. Therefore, the weighting factors V, V_{max} and the tables for the action levels for this assessment procedure were adapted to meet the requirements of EMF Directive see tables 1, 2 , 3.



Todays industrial processes and applications mainly generate pulsed or non-sinusoidal EMF. In the time domain pulsed fields can be decomposed in sinusoidal, trapezoidal, triangular, exponential and constant field components. The exposures linked to these field types can be described by the parameters specified in table 1.

Figure 2. Signal curves (pulses) with sinusoidal or triangular (top left), exponential (top right) and trapezoidal (bottom) waveform.

Table 1. The fields linked to the types of signal curves in figure 2 can be described by the following additional parameters

G	Instead of quantity G use the electric field strength E, the magnetic field strength H or the magnetic flux density B. G(t) indicates the time function, Ĝ the peak value.
T	Pulse duration or pulse width with the following break.
τ_P	Time duration of a field change for sinusoidal, triangular or trapezoidal signal curves from zero to the positive or negative peak value or from the positive or negative peak value to zero respectively. The investigation of τ_P for exponential signal curves shall be performed according to the diagram figure 2. If the individual time durations τ_{Pi} differ, then all these values τ_{Pi} shall be included for further calculations.
T_I	Integration time, where $T_I = \begin{cases} T & \text{where } T \leq 1\,s \\ 1\,s & \text{in all other cases} \end{cases}$
τ_{Pmin}	The smallest value for all time durations τ_{Pi}: $\tau_{Pmin} = \min_i(\tau_{Pi})$
τ_C	Additional quantity for defining exponential signal curves. If the individual time durations τ_{Ci} differ, then all these values τ_{Ci} shall be included for further calculations.
τ_D	Sum of time of all field changes i during a time interval T_I for: - sinusoidal, triangular, trapezoidal signal curves: $\tau_D = \sum_i \tau_{Pi}$ - exponential signal curves: $\tau_D = \sum_i \tau_{Ci}$
f_p	Frequency of a field change, where: $f_P = \frac{1}{4 \cdot \tau_{Pmin}}$
V, V_{max}	Weighting factor, maximum weighting factor $V = \begin{cases} \sqrt{\frac{T_I}{\tau_D}} & \text{where } \sqrt{\frac{T_I}{\tau_D}} \leq V_{max} \\ V_{max} = 2.6 & \text{in all other cases} \end{cases}$
$\left\|\frac{dB(t)}{dt}\right\|_{p,max}$	Maximum time derivative of the magnetic flux density $\left\|\frac{dB(t)}{dt}\right\|_{p,max} = \omega\hat{B} \cdot V = 2\pi \cdot f_P \sqrt{2} \cdot B \cdot V$
$\left\|\frac{dB(t)}{dt}\right\|_{p,mean}$	Mean time derivative of the magnetic flux density $\left\|\frac{dB(t)}{dt}\right\|_{p,mean} = \frac{\omega\hat{B} \cdot V}{\pi/2} = 4 \cdot f_P \cdot \sqrt{2} \cdot B \cdot V$

Results and conclusions

In order to be able to continue to use this proven and very practical assessment procedure solely based on physiological effects in accordance with Directive 2013/35/EU the assessment procedure was adapted to meet the requirements of the EMF Directive, see tables 2 and 3.

Table 2. Action Levels of the maximum time derivative of the magnetic flux density

Action Levels of the maximum time derivative of the magnetic flux density $\left|\frac{dB(t)}{dt}\right|_{p,max}$ in (T/s) according to table B2 of Directive 2013/35/EU

Frequency range	Low Action Level	High Action Level	Action Level for the exposure of limbs to a localised magnetic field
1 Hz $< f_P <$ 8 Hz	$1{,}8 \cdot V/f_P$	$2{,}7 \cdot V$	$8 \cdot V$
8 Hz $< f_P <$ 25 Hz	$0{,}2 \cdot V$	$2{,}7 \cdot V$	$8 \cdot V$
25 Hz $< f_P <$ 300 Hz	$0{,}01 \cdot f_P \cdot V$	$2{,}7 \cdot V$	$8 \cdot V$
300 Hz $< f_P <$ 3 kHz	$2{,}7 \cdot V$	$2{,}7 \cdot V$	$8 \cdot V$
3 kHz $< f_P <$ 10 MHz	$0{,}001 \cdot f_P \cdot V$	$0{,}001 \cdot f_P \cdot V$	$0{,}003 \cdot f_P \cdot V$

Table 3. Action Levels of the mean time derivative of the magnetic flux density

Action Levels of the average time derivative of the magnetic flux density $\left|\frac{dB(t)}{dt}\right|_{p,mean}$ in (T/s) according to table B2 of Directive 2013/35/EU, averaged over the time interval τ_P

Frequency range	Low Action Level	High Action Level	Action Level for the exposure of limbs to a localised magnetic field
1 Hz $< f_P <$ 8 Hz	$1{,}15 \cdot V/f_P$	$1{,}7 \cdot V$	$5{,}1 \cdot V$
8 Hz $< f_P <$ 25 Hz	$0{,}13 \cdot V$	$1{,}7 \cdot V$	$5{,}1 \cdot V$
25 Hz $< f_P <$ 300 Hz	$6 \cdot 10^{-3} \cdot f_P \cdot V$	$1{,}7 \cdot V$	$5{,}1 \cdot V$
300 Hz $< f_P <$ 3 kHz	$1{,}7 \cdot V$	$1{,}7 \cdot V$	$5{,}1 \cdot V$
3 kHz $< f_P <$ 10 MHz	$6 \cdot 10^{-4} \cdot f_P \cdot V$	$6 \cdot 10^{-4} \cdot f_P \cdot V$	$2 \cdot 10^{-3} \cdot f_P \cdot V$

References

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[2] Federation of Industrial Accident Insurance Funds: Accident Prevention Regulation BGV B11 (DGUV rule 15). Sankt Augustin: DGUV, 2001.

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