Co-Exposure to Extremely Low-Frequency Electromagnetic Fields and Sound Pressure in Industrial Environments: Temporal Measurements near Power Transformers

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SHORT ABSTRACT

Co-exposure to high levels of extremely low-frequency (ELF) electromagnetic (EM) fields and high sound pressure (SP) levels can occur in industrial environments. Legislation requires measurements of both ELF EM fields and SP levels in these environments. Therefore, a simultaneous assessment would mean a gain in efficiency. As a first case study, ELF EM and SP exposure is measured near power transformers using temporal measurements. The magnetic flux density at 50 Hz and SP at 100 Hz are highly correlated ($r^2=0.76$, $p<0.05$). Consequently, a linear conversion with a relatively small relative error (8.5%) can be made. Currently, measurements are being carried out to test the sensitivity of this model on spatial displacement and source parameters.

INTRODUCTION

Exposure to high levels of extremely low-frequency (ELF) electromagnetic (EM) fields can occur in industrial environments [1]. Simultaneously, exposures to high sound pressure (SP) levels are common as well [2, 3]. In both cases legislation and worker safety protocols require that an assessment of personal exposure is made [3, 4], often using time-consuming and expensive measurements. However, in some cases both exposures are caused by the same source [5]. Therefore, it is worthwhile investigating whether a single assessment could be used to determine compliance to both norms on ELF EM exposure and SP levels.

Power transformers are an interesting source of both ELF EM and SP. The ELF EM exposure consists out of electric and magnetic field components, of which the latter is dominant near transformers [6]. The magnetic fields are caused by a leakage of fields from the core(s) of the transformer, both in loaded and unloaded conditions, and fields caused by the currents flowing in the windings surrounding the core(s) [6]. The strength of the fields outside of the transformer depends on the load, the construction of the transformer, and the apparent power.

Since the international Agency for Research on Cancer (IARC) has classified ELF EM fields as a possible human carcinogen [7], several studies have focused on ELF EM exposure near transformers [8-12]. In [9], a spatial measurement protocol for exposure measurements near power transformers using an electric and magnetic field analyzer, i.e. a high precision instrument, which requires a longer set up and processing time, is presented. A similar device was used in [10] to perform spot measurements on a predefined location in a transformer cabin. A portable field meter is used in [8, 11, 12] to perform temporal measurements and spot measurements on predefined locations in residential areas.

Power transformers also produce noise, which can be perceived negatively and discomforting [13]. This noise has three sources [5]: vibrations inside the core, so called magnetostriction, vibration of the windings, and noise of the cooling. The effects of magnetostriction are inherent to the material of the core and the exposure caused by this effect is therefore independent of the load, while the vibrations of the windings depend heavily on the load. A power transformer uses an alternating current (AC) provided by the power net at 50 Hz or 60 Hz. The noise cause by magnetostriction operates at even harmonics of these frequencies (100 Hz, 200 Hz, etc. in Europe) [5], while the noise from the windings is situated at only 100 Hz. The noise caused by the fan has a broad frequency spectrum. Although the noise caused by the fan is related to the exposure to ELF EM fields, it is not considered in this study, since we want to focus on the exposure caused by the transformer itself and not all transformers have fan cooling.

Both the ELF EMFs outside a transformer and the sound caused by a transformer are caused by the same fields inside the core and windings of the transformer. Therefore, a relationship could exist between both quantities and measurements of one might predict the other. This avoids a double exposure assessment on a site with a transformer. In this aspect, the acoustic measurements have the advantage that they can be performed with microphones which are of much lower cost than the necessary ELF EM measurement equipment. Moreover, the targeted sound operates at harmonics, which can easily be distinguished in the frequency domain.

The goal of this study is to investigate co-exposure to ELF EM fields and SP levels near a power transformer. First, it is investigated whether both exposures are correlated. Second, a measurement protocol for simultaneous measurement of both quantities using a linear regression is developed. To this aim, both temporal and spatial harmonic measurements of both sound and LF EMFs near power transformers are executed and compared. In this abstract, the authors will focus on temporal measurements.

MATERIALS AND METHODS

Temporal measurements are executed near a power transformer in Kortrijk, Belgium, which is used convert power used for a cafeteria of the University's restaurant. Figure 1 shows the measured transformer and the used measurement equipment. Measurements of the magnetic flux density, sound, and power converted by the transformer are executed over a timeframe from 22h to 17h with a sampling interval of 2 minutes. A perfect synchronization between all measurements was not possible using this set up. Therefore, the data is averaged over 10 minute intervals. This results in 112 samples of all studied quantities.

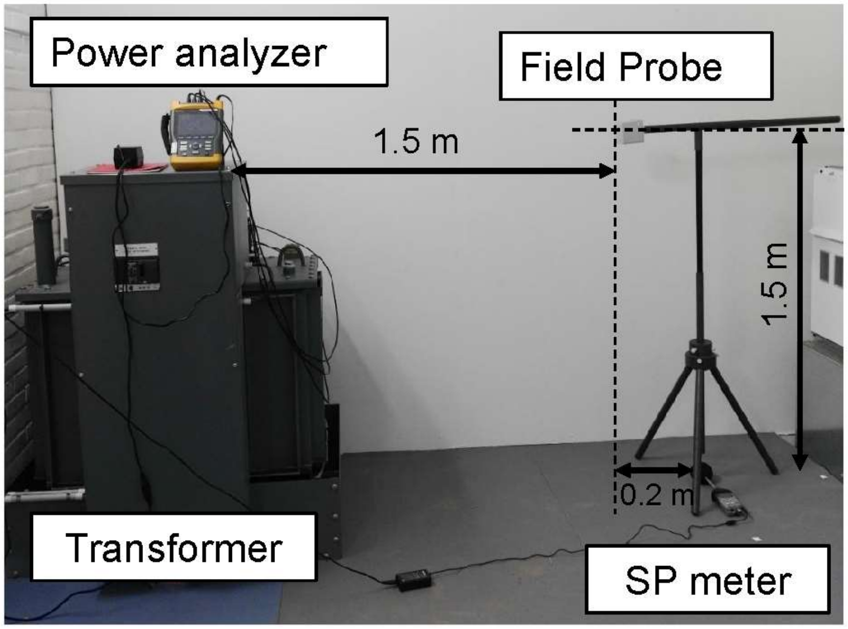

Fig. 1: Measurement set-up near the power transformer

The magnetic flux density (B, unit: T) is measured using an electric- and magnetic-field analyzer of type PMM EHP-50C (accuracy magnetic field: 6%). The detection range is 1nT-10 mT for the magnetic field. The field probe is connected to a laptop using a fiber-optic cable, in order to avoid influence of the ELF fields on the communication. The field probe is placed at a height of 1.5 m at a distance of 1.5 m from the transformer. The SP levels (P, unit: Pa), are measured by a Svantek 959 SP level analyzer. This measurement device performs temporal measurements of the pressure levels and performs a fast-fourier transform in order to obtain the frequency components of the SP levels. In this study, we have focused on the 100 Hz component, caused by both magnetostriction and load-dependent noise, and the 400 Hz component which is mainly caused by magnetostriction. The SP meter is placed at a distance of 1.7 m from the transformer at ground level, in order to minimize reflections of the floor. Simultaneously, the apparent power (S, unit: kVA) on the transformer is registered using a power analyzer (Fluke 434).

The temporal measurements are first correlated in order to investigate the relationship between the different quantities. Then two regression models are established using 56 (50% of the samples) randomly drawn design values and an equal amount of control values. First, a linear regression is executed between B(50 Hz) and P(100 Hz):

$$\hat{B}[\mu T] = \beta_0 + \beta_1 \times P(100\ Hz)[Pa] \quad (1)$$

The pressure (P) depends both on the load and the magnetic properties of the transformer in this case. Second, a multiple linear regression is executed; in order to investigate whether additional information about the load-independent sound improves the estimation of the magnetic field:

$$\hat{B}[\mu T] = \beta_0 + \beta_1 \times P(100\ Hz)[Pa] + \beta_2 \times P(400\ Hz)[Pa] \quad (2)$$

The remaining 56 samples are then used to determine the error-on-prediction (err) of both regression models:

$$err\ [\%] = \left|\hat{B} - B\right|/B \qquad (3)$$

The intercept, inclinations, and mean error are stored and the regression is executed again using 56 new samples. This process is repeated 100 times in order to obtain statistics for the studied quantities.

RESULTS

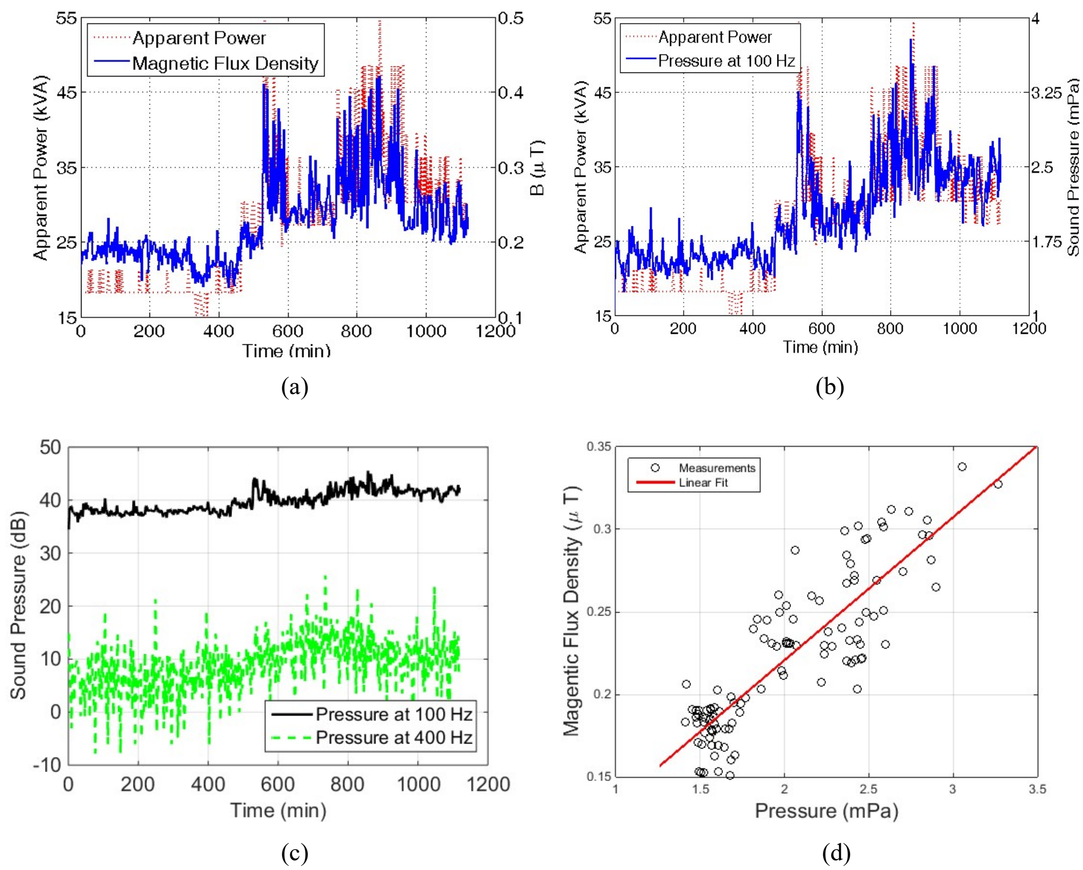

Figure 2: Results of the temporal measurements: (a) Apparent power (S) and magnetic induction (B) over time, (b) Pressure (P) at 100 Hz and S over time, (c) P(100 Hz) and P(400 Hz) over time, and (d) A scatterplot of measured B at 50 Hz and P at 100 Hz.

Figure 2 shows the results of the temporal measurements. Fig. 2 (a) shows the temporal variation of S and B at 50 Hz. Since the external magnetic flux is caused by power consumption, a high correlation (r^2=0. 94, $p<0.05$) between both quantities was expected. Both quantities are low during night and increase during daytime as production in the kitchen (and consequently power conversion) starts. Fig. 2 (b) shows the evolution of the sound pressure at 100 Hz and S. Both quantities are again highly correlated ($r^2=0.95$, $p<0.05$). Fig. 2 (c) shows the evolution of the SP levels at 400 Hz over time, along the evolution of P at 100 Hz. The sound at 400 Hz depends less on the converted power ($r^2=0.60$, $p<0.05$), which was expected since the harmonics caused by the load-dependent noise decay more than those caused by magnetostriction [5], which in its turn is load-independent. The sound pressure at 100 Hz is on average 31 dB higher than at 400 Hz. However, in A-weighted values [14], corrected for human perception, the difference is only 16 dB. The 100 Hz sound does remain the dominant component.

Fig. 2 (d) shows a scatterplot of P(100 Hz) and B(50 Hz) averaged over 10 minute measurement intervals. The correlation (r^2=0.76, $p<0.05$) between P(100 Hz) and B indicates a strong relationship. There are differences between both quantitate due to different characteristics of the environment regarding sound and electromagnetism. We expect this correlation to be higher if the synchronization of the measurements can be improved.

The result of the linear regression using Eq. 1 is also shown in red. The linear fit is obtained using the averaged intercept β_0 and slope β_1 obtained for Eq. 1, which are 0.048 ± 0.009 µT and 87 ± 4.9 $\mu T/Pa$, respectively. The mean error-on-prediction is 8.5% $\pm$ 0.7 %, which is of the same order of magnitude as the accuracy of the measurement devices. The multiple linear regression results in a slightly lower mean error-on-prediction 8.3% $\pm$ 0.7 %. The correlation of the second model (r^2=0.77, $p<0.05$) is also not much higher than that using the linear regression.

These values are only valid for the investigated set up and power transformer. A sensitivity study of these parameters has to be executed in order to prove the applicability of the regression model in more general exposure situations. We are currently executing measurements in order to determine whether these coefficients depend on the distance to the transformer, using spatial measurements, and on the actual transformer type.

CONCLUSIONS

Co-exposure to extremely low-frequency (ELF) electromagnetic (EM) fields and sound pressure (SP) levels near power transformers is studied using temporal measurements. The measurements show that the magnetic flux density at 50 Hz and SP at 100 Hz are highly correlated (r^2=0.76, $p<0.05$). A linear regression model between both quantities has a relatively small error of 8.5%. This indicates that a predictive model could be established between both quantities. However, this model needs to be validated in other exposure situations. To this aim, spatial measurements and measurements near different sources are currently executed.

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