Measuring system of low frequency electromagnetic field on board of ships

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Abstract **-** The way of measurement of low frequency electromagnetic field intensity is presented. Computer measurement system is described, which can be used for RMS value isotropic measurement and recording of electric and magnetic components of electromagnetic field time waveforms. Later the off-line time-frequency analysis of the recorded signals can be done. Selected results of measurements made onboard Gdynia Maritime University research-training vessel are performed.

I. Introduction

On board the sea-going vessel, the low frequency electromagnetic field of high intensity can be found, because of running generators and several electrical energy high power consumers, like electrical motors or power electronic converters. They can be not accepted not only by the reason of direct interaction on people, but also by the reason of ineligible interaction on technical equipment. Occurrence of strong electromagnetic field can also cause phenomena which initiates accidents, and in this way disturb the operation of many different control systems. So, these problems are important from practical point of view, because electromagnetic disturbances directly affect reliability of the objects, what in shipboard environment is strongly related with navigation safety. These phenomena are also not indifferent for safety of people staying near sources of electromagnetic fields. There are standards, which establish borders of zones of protective fields and electromagnetic radiation and principles of admissible exposition in individual zones [2, 3].

Taking into account the analysis of the measurements results made onboard research-training vessel m/v “Horyzont II”, preliminary evaluation of electromagnetic field (EMF) intensity for frequency range from 5 Hz to 400 Hz was carried out [1]. Electrical component of electromagnetic field intensity was found negligible. High intensity magnetic fields areas were located. The high dynamics of this intensity level changes was observed.

In the frequency range below 2 kHz, the recorded values of magnetic field strength exceeded the lower border of hazard zone, which divides hazard and intermediate zones.

It should be taken into account, that results of exposure are very strong dependent, not only on EMF strength, but also on time duration, and that EMF time-varying exposure limits are changing with EMF frequency and radiation level, which affects the men. That’s why it is necessary to make spectral analysis, which will cover characteristics of the recorded signal.

II. Measurement system

The electromagnetic field intensity measurements in low frequency range were performed using measurement system, which enables simultaneous isotropic measurement of RMS value of both the electric and magnetic field components, defined for each 0,5 s period, and also time-frequency analysis of the recorded time waveforms of these fields (Fig. 1).

MASCHEK ESM-100 H/E field-meter, which was applied in this system, enables measurements within the range 5 Hz up to 400 kHz in four successive measurement sub-ranges: “all” - from 5 Hz to 400 kHz, at frequency “50 Hz”, “low” - from 5 Hz to 2 kHz and “high” - from 2 kHz to 400 kHz [4]. RMS values of the electric field intensity E in the range from 0,1 V/m to 100 kV/m and magnetic field intensity H in the range from 1 nT to 20 mT, were measured simultaneously in three directions:

$$H = \sqrt{H_x^2 + H_y^2 + H_z^2} \qquad (1)$$

$$E = \sqrt{E_x^2 + E_y^2 + E_z^2} \qquad (2)$$

The ESM-100 H/E field meter is controlled by personal computer using MASCHEK Graph ESM-100 Documentation Software, connected to the meter with the fibre optic cable. The change of settings, on-line data recording start and stop, transfer of the data and bar-graphs is possible.

Data recording of the magnetic field intensity instantaneous values was carried out with a/d converters data acquisition (DAQ) board, which was connected to the analogue outputs of ESM-100 M/E field meter. Four wide-band (5 Hz - 400 kHz) analogue outputs of this meter can be utilized for measurements of time waveforms of magnetic and electric fields components in three directions: x, y, z, with output voltage range from 0 to 600 V.

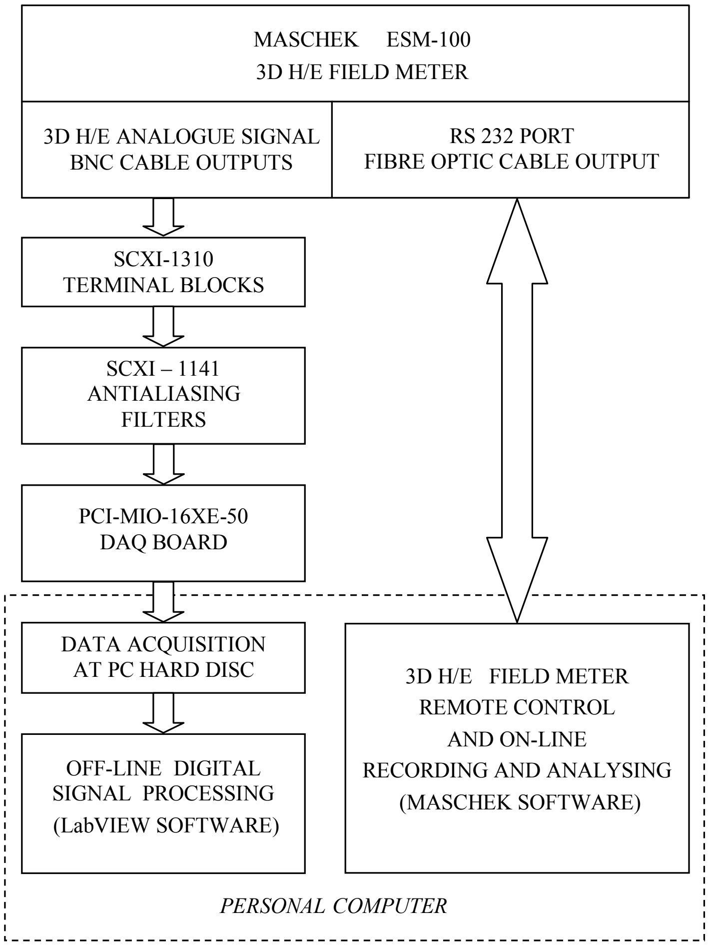

Fig. 1. Digital measurement system for assessment of low frequency magnetic and electric fields intensities

In the beginning, the measured analogue signal is conditioned with the use of National Instruments sub-assemblies (amplified and filtered) and next is sent to a/d converter (with 16-bit resolution and 20 kHz sampling frequency). Matching of the signal level to the a/d converter DAQ board input is realised by the input amplifier with the programmable gain: 1, 2, 5, 10, 20, 50 or 100. So at the output it is possible to have the measured voltage signals in the range of +/-5 V.

Elliptical low pass filters (8-th order) with cut-off frequency programming, eliminate phenomena of aliasing.

Measurement discrete signals are next analysed (off-line) with the use of virtual instruments (LabVIEW software).

III. Digital signal processing procedures

FFT analysis is the most simple method of signal spectrum evaluation, but in such a case it is not possible to find with some accuracy local effects, which occur in the signal with the parameters changing in time. At the same time, with the limited number of recorded samples of the signal (constant sampling frequency), FFT procedure doesn't assure enough frequency resolution of signal analysis. To improve the resolution of spectral analysis, Chirp-Z Transform (CZT) was applied [5].

Discrete Transform of CZT N - element time sequence of signal $x(n)$, where $0 \leq n \leq N-1$, is defined for the following $M+1$ frequencies f_k normalized with regard to sampling frequency f_s:

$$f_k = f_0 + k\Delta f, \qquad k = 0,...,M \tag{3}$$

Then the Fourier spectrum X_k of the analysed signal can be calculated in a narrow frequency range f_{window}, with the resolution Δf, defined by the user:

$$\Delta f = \frac{f_{window}}{M} \tag{4}$$

where: $f_{window} = [f_0; f_g]$, and $f_g = M\Delta f$.

For identification of signal in time periods and its spectrum distribution, time-frequency methods of analysing were used. Such procedure allows to determine with some time resolution the moments, when the analysed signal components of different frequencies occur. So this way, the sources of high level electromagnetic fields can be localized in the tested environment. With regard to the fact, that digital signal processing was not performed on-line, it was decided to apply fast algorithm STFT (Short-Time Fourier Transform), and adaptive transform, with a long processing time.

The STFT based spectrogram is defined as the square of the STFT [6]:

$$SP[m\Delta M, n] = \left| \sum_{i=0} x(i)\gamma(i - m\Delta M)\exp(-\frac{j2\pi ni}{N}) \right|^2 \tag{5}$$

where: N denotes the number of frequency bins, ΔM denotes the time sampling interval and $\gamma(i)$ is dual function of time-shifted prototype function $h(i)$.

If the frequency contents of the analyzed signal doesn't change rapidly, then the STFT spectrogram can be applied with relatively wide window function, to obtain a good frequency resolution.

The adaptive spectrogram method is an adaptive representation based spectrogram, calculated with [6]:

$$AS[i,n] = 2\sum_{k=0}^{D-1} |A_k|^2 \exp\{ -\frac{[i-i_k]^2}{\alpha_k} - (2\pi)^2 \alpha_k [n - f_k - \beta_k i]^2 \} \tag{6}$$

where: $\alpha_k, i_k, f_k, \beta_k$ are the four-tuple parameters of the linear chirp modulated Gaussian prototype function $h_k(i)$, the parameter D denotes the total number of elementary functions used by $h_k(i)$, and A_k is the weight of each individual $h_k(i)$.

The adaptive spectrogram reaches the best joint time-frequency resolution, if the analysed signal is a sum of linear chirp modulated Gaussian function. The computation speed of the adaptive spectrogram increases exponentially with the analyzed data size.

IV. Experimental research

Experiments were performed in engine room of Gdynia Maritime University research-training vessel m/v "Horyzont II". Electric and magnetic field intensity components were recorded close to the generator No 1 (3 phase, 400 V, 50 Hz, 376 kVA) with the ESM-100 M/E field meter, which was fixed to the wooden tripod (Fig. 2). Ball sensor of the meter was at the height of 132 cm from the floor and in the distance of 57,5 cm from the generator body. The centre of the generator shaft was 46 cm over the floor plates.

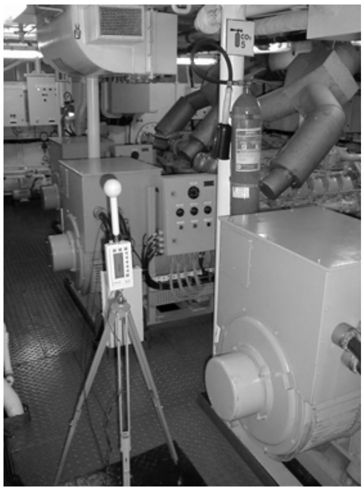

Fig. 2. Measurement of the Generator No 1 electromagnetic field intensity, in the engine room of the research-training vessel m/v "Horyzont II"

During the experiments, the next generator No 2 was also started and connected to the main switchboard, and the additional energy consumers were switched on, like: air condition heaters, fans, engine room supply and exhaust fans. During the measurements, the great dynamics of changes of magnetic field intensity was observed, which depended on the time of the measurements (Fig. 3). Recorded time waveforms of magnetic field intensity show, that the main field component is 50 Hz, modulated with slow changing random component (Fig. 4). In the signal spectrum there are also periodical components, harmonics of the main 50 Hz (Fig. 5).

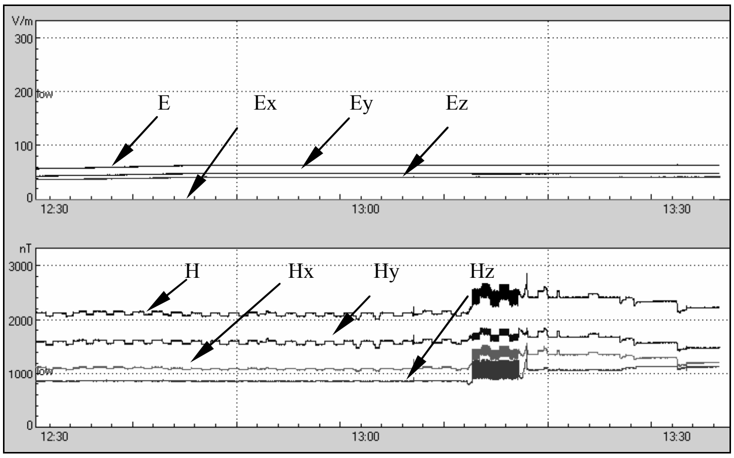

Fig. 3. Records of RMS values of electric and magnetic fields intensities, measured close to the Generator No 1, with the "low" frequency range (from 5Hz to 2 kHz)

Additional measurements of the electromagnetic field were performed for the running bow thruster electric drive. Bow thruster squirrel cage motor was supplied from the frequency converter. The measurements of the field intensity (electrical and magnetic components) were done for different voltage frequencies at the output of frequency converter.

During research works the high dynamics of magnetic field level changes was observed, which was dependent on inverter output voltage frequency (Fig. 6). In the investigated environment there was a low intensity electric field, not exceeding 5 V/m.

On the base of CZT algorithm, the signal detailed band analysis, with the variable resolution, was prepared for the frequency range below 2 kHz (Fig. 7). Such approach, comparing to the FFT analysis, gives the big shortening of the analysis time, with the same accuracy for the different bands.

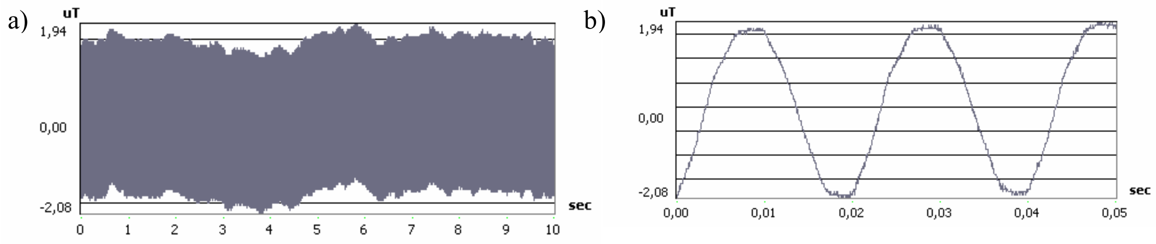

Fig. 4. Time waveforms of magnetic field intensity “y” component, for the time periods: 10 s (a) and 0,05 s (b)

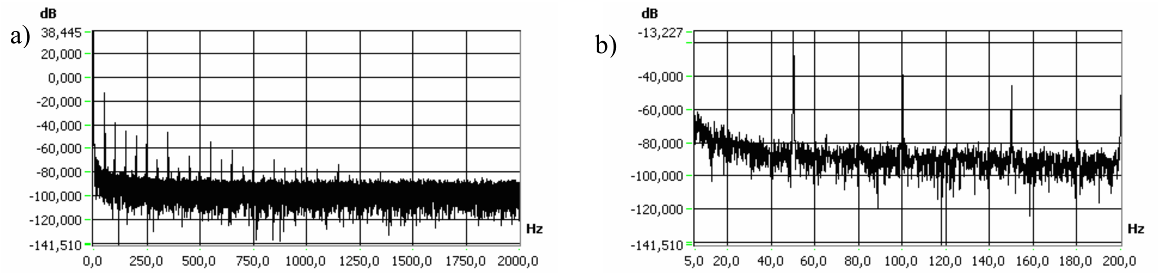

Fig. 5. Frequency spectrum of magnetic field intensity “y” component in the frequency range: up to 2 kHz (a), from 5 Hz to 200 Hz (b)

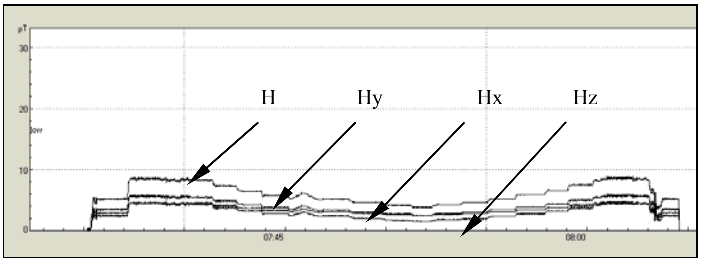

Fig. 6. Records of RMS values of magnetic field intensity, measured for different voltage frequencies at the output of frequency converter, with the “low” frequency range (from 5Hz to 2 kHz)

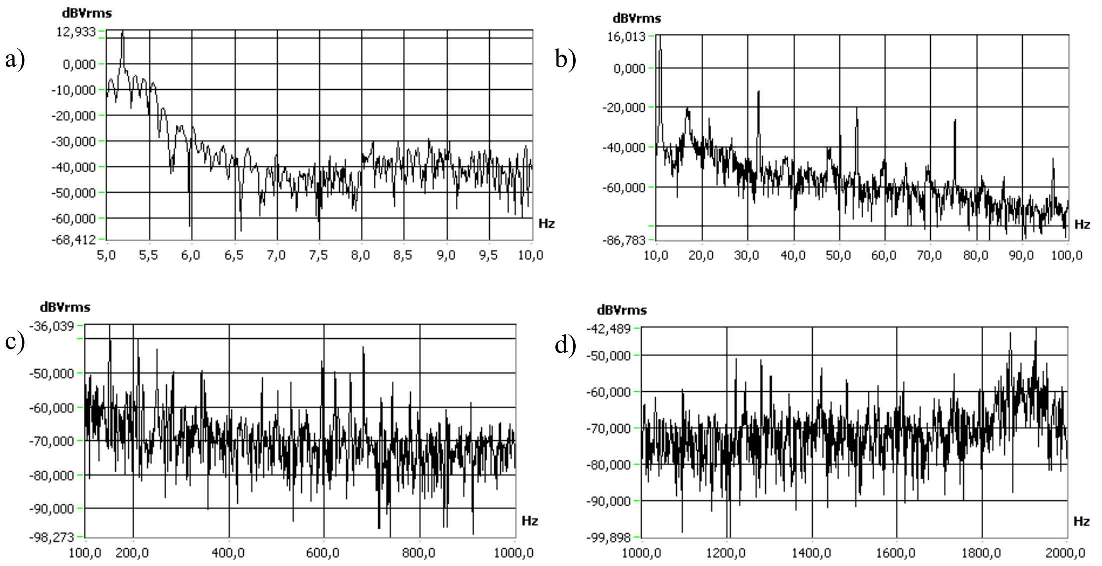

Fig. 7. Frequency spectrum of magnetic field intensity in “y” direction for the range: 5 Hz to 10 Hz *(Δf = 0,01 Hz)* (a), from 10 Hz to 100 Hz *(Δf = 0,1 Hz)* (b), from 100 Hz to 1000 Hz *(Δf = 1 Hz)* (c), from 0,1 kHz to 2 kHz *(Δf = 10 Hz)* (d)

Unfortunately the performed frequency analysis didn’t make possible the decomposition of the analysed signal in the time domain. During the experiments, the frequency converter output frequency was changed fine from 0 to 50 Hz. The STFT of analysed signal with narrowband Hanning window shows, that the time-dependent spectrum has high frequency resolution, but poor time resolution. With the wideband window, the time-dependent spectrum has poor frequency resolution, but high time resolution (Fig. 8a). The instantaneous high resolution of the method is not possible for both domains.

Extremely high resolution can be obtained applying the adaptive spectrogram (Fig. 8b).

a) b)

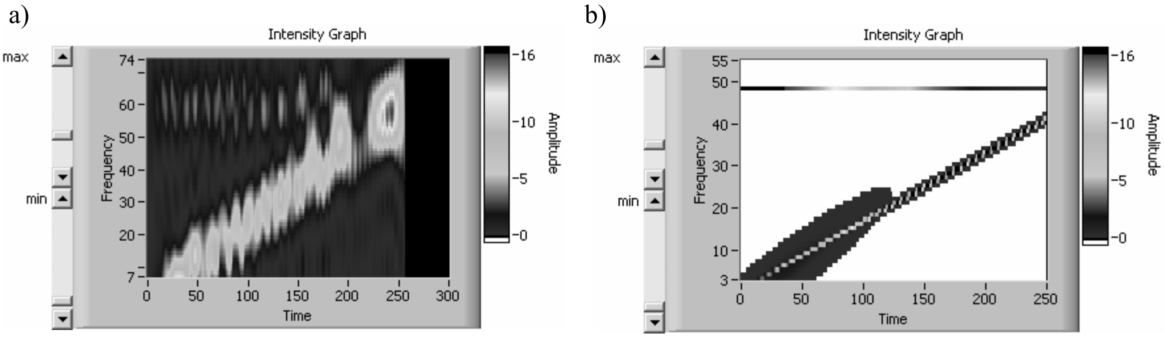

Fig. 8. STFT – based spectrogram with wideband Hanning window (a) and adaptive spectrogram (b) of magnetic field intensity in “y” direction for different voltage frequencies at the output of frequency converter, approximate linear changing from 0 Hz to 50 Hz

V. Final remarks

The proposed measurement system allows the recording of the actual values of the electromagnetic field intensity and after that spectral analysis of this field. It is especially important, when the measurements are made in direction on environment, to verify, that the permissible levels of electromagnetic field are kept.

The CZT procedure applied in the channel of discrete measured signal processing, increased the accuracy of frequency spectrum determination and shortened the signal processing time.

Performed “time-frequency” analyses of the recorded time waveforms of magnetic field intensity made possible the signal identification in time periods. The authors were able to determinate with some time resolution the moments of the analysed signal different frequency components.

Two methods of signal analysis were applied: STFT and adaptive. The adaptive algorithm has better joint time and frequency resolution, then the STFT spectrogram, but it requires more computation time, which is suitable for offline analysis.

References

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