

THE INFLUENCE OF FREQUENCY CONTROLLED AC DRIVES ON VIBRATION AND AUDIBLE NOISE LEVEL ON SHIPS

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Abstract – The correlation between electric disturbances and vibration, as well as audible noise in marine frequency controlled AC drive systems was examined. The destructive influence of these factors on quality of life of a sea going vessel's crew was indicated.

Keywords: frequency converters, electromagnetic disturbances, vibration, audible noise

1. INTRODUCTION

In the recent years it is possible to observe a big amount of frequency converters applied to different drive systems with induction motors on ships, like in cranes, mooring winches, pumps, fans and also in ship main drives (propellers). The power of the small fan motor can be less than 1kW, but in the case of ship main engine, can reach even 6MW. Efficiency of the frequency controlled AC drive system is very high, the motor speed control is very precise, overhaul is easy and not very frequent, and the frequency converters are not so expensive now.

But frequency converters have some disadvantages, because they generate electromagnetic disturbances in the wide frequency range. This happens due to the rectifier diodes and inverter transistors' commutation, which can be switched with the frequency from 2 kHz to 20 kHz. These disturbances, that are conducted to the system supply net and also to the supply line of a motor, increase the vibrations of the whole drive system. Vibration components, laying in the acoustic frequency range, are causing significant increase of audible noise emitted by the drive system [1]. Those excessive vibrations and noise can be observed especially on ships, where many such systems are installed.

The high level of electromagnetic field as well as vibration and audible noise occurring on sea going vessels have ineligious influence on the crew. They cause general attenuation of concentration of note and memory, but sometimes disturbances of dreams, nervousness, pains and other diseases.

2. ANALYSIS OF LABORATORY EXPERIMENTS

The experiments with a model of the marine drive system with a frequency converter were performed in laboratories of Department of Ship Automatic Control at Gdynia Maritime University.

In the beginning, the experiments were performed with the squirrel cage asynchronous motor connected directly to the output of the frequency converter. At the second stage, to confirm the thesis of the correlation between harmonics contents in motor voltage and current waveforms and acoustic noise of the motor, the sinusoidal LC passive filter was connected at the output of the frequency converter. During tests, motor was nominally loaded with the use of the DC generator connected to adjustable resistor.

The authors were able to apply only one typical (factory made) output sinusoidal LC passive filter, but in the future the special adaptive filter will be designed and tested.

The data acquisition of audible noise level (A-weighted), voltage and current waveforms was carried out with the digital measurement system (Fig.1), for different switching frequencies of the inverter transistors and inverter output frequencies.

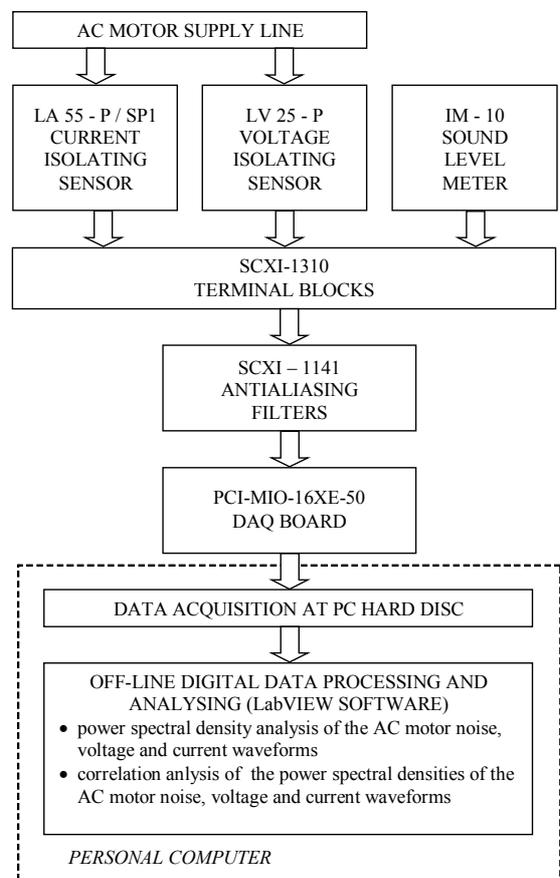


Fig. 1. Block diagram of digital system for measurement and analysis of audible noise and disturbances in the motor supply line

The correlation between the power spectral density of audible noise level and electric disturbances in the supply line of the motor, was examined in the off-line mode.

Power spectral density $G_n(k)$ was calculated with the use of a Fourier transformation, where the procedure of the spectrum estimator averaging was made at time intervals (section averaging). The section averaging means, that for sampling period Δt , the time series of analyzed signal $x(i\Delta t)$ with the length N , is divided in Q time intervals with the N/Q length, which is chosen according to the selected resolution of analysis. For each q -th time interval, the power spectral density estimators were calculated using following equation:

$$G_n(k, q) = \frac{2\Delta t}{K} |X_k|^2 \quad (1)$$

where: X_k – components (ordinates) of the $x(i\Delta t)$ signal Fourier transformation (DFT), and $K = N/Q$.

X_k components can be defined as follows:

$$X_k = \sum_{i=0}^{K-1} x(i\Delta t) \exp\left(-j \frac{2\pi k i}{K}\right) \quad (2)$$

Next, for each frequency f_k , these q estimators of power spectral density were averaged:

$$G_n(k) = \frac{G_n(k,1) + G_n(k,2) + \dots + G_n(k,Q)}{Q} \quad (3)$$

Correlation factor for two sets of values, representing power spectral densities, was defined:

$$\rho = \frac{1}{0,5K-1} \frac{\sum_{k=1}^{0,5K} (G_{1n}(k) - \overline{G_{1n}(k)}) (G_{2n}(k) - \overline{G_{2n}(k)})}{\sigma(G_{1n})\sigma(G_{2n})} \quad (4)$$

where $\overline{G_{1n}(k)}$, $\overline{G_{2n}(k)}$ are the average values of power spectrum densities, for the set 1 and set 2 respectively, $\sigma(G_{1n})$ and $\sigma(G_{2n})$ are their standard deviations.

3. SELECTED RESULTS

The motor voltage, current and audible noise waveforms were recorded in digital form, for the few different output voltage frequencies f_{out} (20 Hz, 23 Hz, 25Hz, 40 Hz, 46 Hz, 50 Hz) and few different inverter's transistors switching frequencies f_{sw} (3 kHz, 6 kHz, 12 kHz).

Using LabVIEW software power spectral density analysis of all recorded waveforms was carried out.

Selected results are shown in Fig. 2 and Fig. 3.

Fig. 2 illustrates power spectral density of motor voltage and current waveforms and the sound level emitted by the motor, which was supplied with voltage frequency $f_{out} = 46$ Hz and switching frequency $f_{sw} = 6$ kHz.

Fig. 3 shows the same power spectral density of motor voltage and current waveforms and the sound level emitted by the motor, but when the output LC passive filter was applied.

The presence of 6 kHz component (the switching frequency f_{sw}) can be seen on each diagram in Fig. 2 and Fig. 3.

Factory made sinusoidal output filter decreases the level of power spectral density of AC motor voltage and current waveforms. In the case of the sound level, only some components were reduced in frequency range below 1 kHz, for bigger frequencies significant reduction of power spectral density was not observed.

Taking into account (4), correlation factors for sets of values, representing power spectral densities of the AC motor voltage, current and sound were calculated.

Selected results are performed for one motor voltage frequency 46 Hz and two switching frequencies - 6 kHz and 12 kHz, without and with the output filter:

- in Table 1 for voltage and current,
- in Table 2 for voltage and sound,
- in Table 3 for current and sound.

The correlation between voltage and current power spectrum densities was confirmed (Table 1), correlation factor increased when the output filter was applied.

TABLE 1. Correlation factor of voltage and current power spectrum densities

$f_{out} = 46$ Hz	f_{sw} [kHz]	Correlation factor
without the filter	6	0,487
	12	0,465
with the filter	6	0,606
	12	0,557

The correlation between voltage and sound power spectrum densities was not observed in the case, when the motor was supplied without filter (Table 2), but with the filter the correlation was significant.

TABLE 2. Correlation factor of voltage and sound power spectrum densities

$f_{out} = 46$ Hz	f_{sw} [kHz]	Correlation factor
without the filter	6	- 0,017
	12	0,013
with the filter	6	0,291
	12	0,541

The correlation between current and sound power spectrum densities was much higher in the case when motor was supplied without filter (Table 3), comparing to the correlation between voltage and sound power spectrum densities (Table 2).

TABLE 3. Correlation factor of current and sound power spectrum densities

$f_{out} = 46$ Hz	f_{sw} [kHz]	Correlation factor
without the filter	6	0,066
	12	0,159
with the filter	6	0,174
	12	0,421

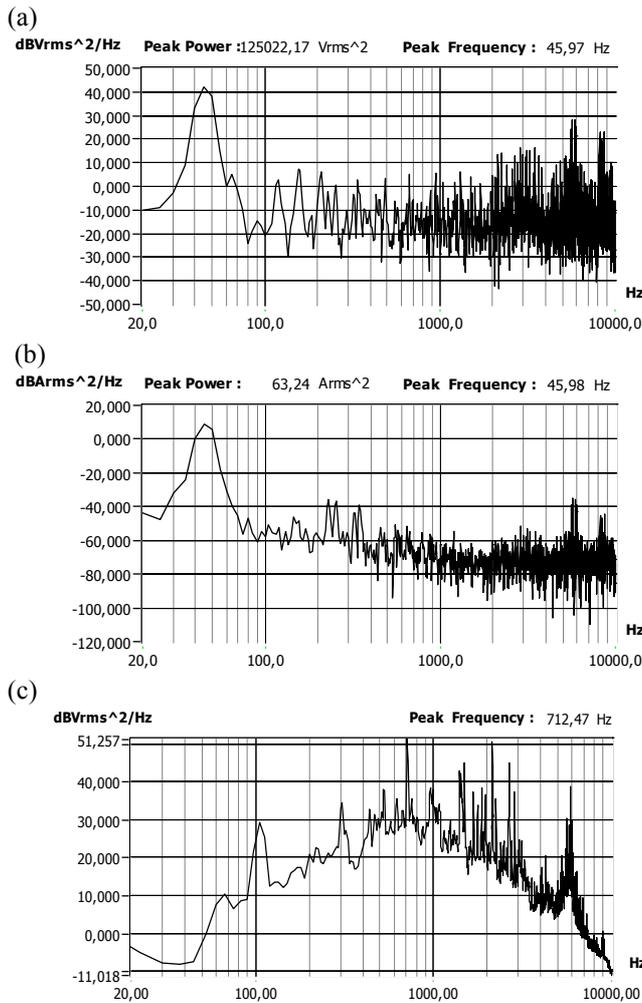


Fig. 2. Power spectral density of the voltage (a), current (b) and sound (c) waveforms, at $f_{out} = 46$ Hz and $f_{sw} = 6$ kHz, without output LC passive filter

4. CONCLUSIONS

The purpose of the research works carried out by the authors is to reduce the level of electric disturbances and audible noise in marine frequency controlled AC drive systems [2] and in this way to improve the quality of crew life.

Looking at the data in Tables 1, 2, 3, it can be seen that applying the output filter brings not only the reduction of the level of electric disturbances in AC motor voltage and current waveforms, but also has an influence on audible noise of the motor.

So it means, that further deeper research works should be continued. It will be necessary to design and test new output adaptive filters, applied in motor supply line, and optimize their frequency characteristics.

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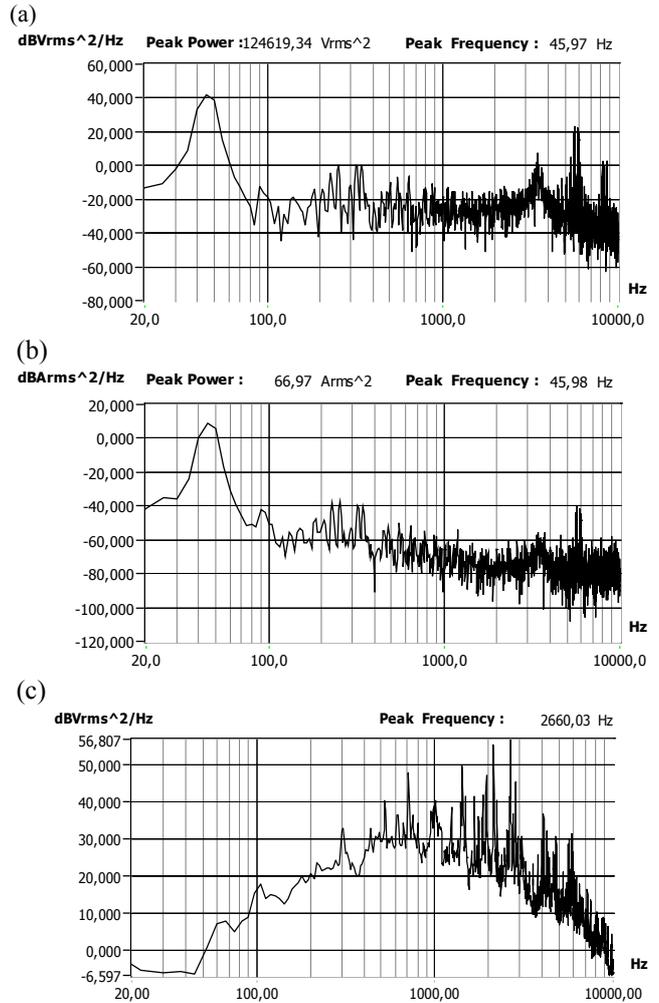


Fig. 3. Power spectral density of the voltage (a), current (b) and sound (c) waveforms, at $f_{out} = 46$ Hz and $f_{sw} = 6$ kHz, when the output LC passive filter was applied.

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