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## Technical evaluation of marine auxiliary diesel engine on the basis of parameters synchronous generator

*Abstract: The article presents a method for evaluating the technical condition of selected structural elements of the reciprocating internal combustion engine driving a synchronous generator. The results of measurements of the electric generator parameters are the diagnostic information source. On this basis it is possible to determine the instantaneous angular speed marine engine crankshaft which, in turn, is the basis for reasoning about the correctness of the process of fuel combustion in the engine cylinders, and efficiency of the speed controller. By that means one can define the technical condition of the fuel equipment, sealing the piston-rings-cylinder system, and the correctness of the process of the working medium exchange in the engine cylinders.*

*Keywords: technical diagnostics, marine diesel engines, working spaces, diagnostic information, diagnostic parameters.*

### Ocena stanu technicznego okrętowego tłokowego silnika spalinowego na podstawie badań parametrów elektrycznych prądnicy okrętowej

*Streszczenie: W artykule przedstawiono metodę oceny stanu technicznego wytypowanych elementów struktury konstrukcyjnej pomocniczego tłokowego silnika spalinowego napędzającego prądnicę synchroniczną. Źródłem informacji diagnostycznej są wyniki pomiarów parametrów elektrycznych prądnicy. Na ich podstawie możliwe jest określenie chwilowych prędkości kątowych wału korbowego silnika okrętowego, co stanowi podstawę do wnioskowania o prawidłowości przebiegu procesu spalania paliwa w cylindrach silnika oraz o sprawności pracy regulatora prędkości obrotowej. Pozwala to na określenie stanu technicznego aparatury paliwowej, szczelności zespołu tłok-pierścienie-cylinder oraz poprawności przebiegu procesu wymiany czynnika roboczego w cylindrach silnika.*

*Słowa kluczowe: diagnostyka techniczna, silnik okrętowy, przestrzenie robocze, informacyjność diagnostyczna, parametr diagnostyczny.*

## 1. Introduction

Auxiliary diesel engines which are not equipped with indicator valves are widely used in the Polish Navy. Such marine engines are mainly used in ships power plants, less for the ship propulsion. The absence of indicator valves causes certain diagnostic problems, and sometimes makes impossible the parametric evaluation their technical conditions. They are operated according to so-called overhaul life strategy, and only endoscopic examinations are carried out [1, 2, 3, 4].

In the last years they have started to develop an alternative to optical test, methods for assessing the technical condition of auxiliary engines [5, 6, 7]. More commonly measurements of selected engine construction elements vibrations are used. The method for evaluating the technical condition of the diesel engine operating spaces (inside cylinders, inlet and outlet manifolds), and fuel equipment on the basis of pressure pulses in exhaust manifold measurements was developed [5]. Another innovative method for evaluating the technical condition of certain structural elements of the selected engine

is being developed lately. This method is based on measurements of some energetic parameters of the synchronous generator driven by such an auxiliary diesel engine.

This method is to allow to evaluate the technical condition of the engine operating spaces, fuel equipment, and timing. One of the advantage of the method is to be a complete lack of interference in the engine structure, ease of measurements and versatility – may be used virtually for all diesel engines driving synchronous generators.

## 2. Principle of the method

The developed method for determining the technical condition of the diesel engine driving the synchronous generator is based on measurements of instantaneous values of phase-to-phase voltages of the generator and synchronizing them with the engine cycle of operation.

The basis for the development of this method is the fact that there is a rigid coupling between the engine crankshaft and the rotor of the generator so that only torsional vibrations of a small amplitude

may appear, and the generator is synchronous. Such a connection causes that the instantaneous angular speed of the crankshaft and the rotor is practically the same. Therefore, the information on the engine crankshaft angular velocity can be acquired by measuring the instantaneous values phase-to-phase voltages of the generator. Changes of shapes of the voltage waveforms result from fluctuations of the angular speed of the engine crankshaft.

Knowledge of the crankshaft angular velocity as a function of time enables to specify uneven engine running that depends, among others, on the number of cylinders, engine load torque, and its technical condition. Momentary crankshaft angular accelerations result from gas forces coming from engine cylinders. In case of a correct adjustment of the engine and a good technical condition (the same combustion pressures), the forces are the same, so values of the crankshaft angular accelerations are the same, too. Regarding four-stroke engines (most often applied in ship power plants) forces coming from all cylinders are recorded during two revolutions of the engine crankshaft. In the case of appearance of an anomaly in the course of momentary crankshaft angular velocity it is possible to conclude about damages in one of piston-rings-cylinder system, improper adjustment or malfunction of the fuel supply system.

Due to the unique processes occurring in the internal combustion engine the authors decided to record parameters measurements for at least 20 cycles of operation. In the case of engine crankshaft speed  $1500 \text{ min}^{-1}$  it lasted 2 seconds. This allows the use of synchronous averaging tested parameters of the engine. As the synchronizing signal served vibration accelerations measured on engine fuel injectors. That signal has a much higher amplitude during injection (Fig. 1.), and therefore is quite convenient to synchronize measurements of engine energetic parameters according to its cycle of operation.

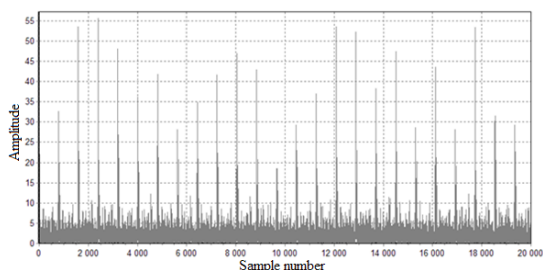


Fig.1. The course of recorded vibration signal at one of engine injectors as a function of the sample number

Recorded vibration signal occurs exactly once during the cycle of operation of a four-stroke engine, and allows you to split the measured voltage signal to “fragments” correspond to the duration of one cycle of the engine, as shown in Fig. 2.

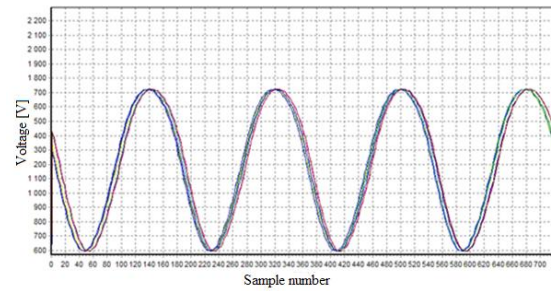


Fig.2. Voltage waveform after splitting it into sections corresponding to the operating cycle of the engine, as a function of the sample number

The next step is to determine the averaged course of the test signal, that enables to minimize the impact of random errors. View of voltage waveform as a function of the sample number is shown in Fig.3.

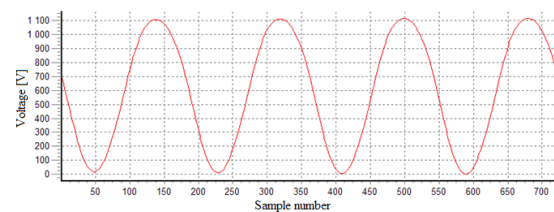


Fig. 3. Averaged phase-to-phase voltage waveform as a function of the sample number

In addition, measurement of injector vibrations allows you to specify the time of each working stroke in engine cylinders, which can be applied to the voltage waveform. This allows you to split the graph into sections corresponding to the cycle of operation each of the cylinders (Fig. 4).

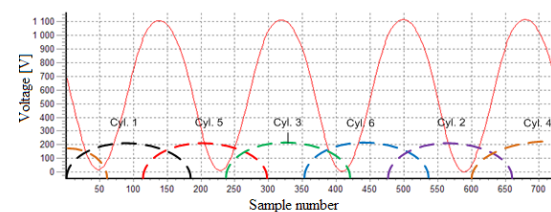


Fig.4. Averaged phase-to-phase voltage waveform as a function of the sample number. Fragments of operation cycles corresponding to particular cylinders are marked

In the case of the growth of unevenness of the angular crankshaft velocity due to the engine load torque or a deteriorating technical conditions of the tested object, one can notice some deformations phase-to-phase voltage waveform as a function of the sample number that is identical with time. An example of a graph describing this phenomenon is shown in Fig.5.

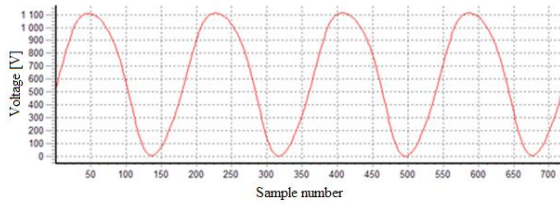


Fig.5. Distorted, as a result of engine load torque, phase-to-phase voltage waveform as a function of the sample number

Waveforms distortion, shown as a function of the sample number, result from unevenness of the crankshaft angular velocity, and thus the generator rotor. To obtain momentary crankshaft angular speed from recorded as a time function voltage waveforms, one has to compare the results with the reference signal (sine course). The course of the reference signal can be obtain in two ways: by carrying out approximation of the measured samples using the sine function limited to the first level or on the basis of spectral analysis of this signal, where the course is “rerecorded” on the basis of the first harmonic of the signal for the real and imaginary values. The course obtained in this way imposed on measurements result as time function is shown in Fig.6.

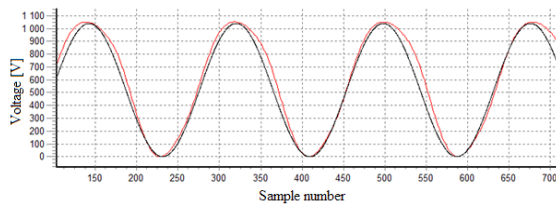


Fig.6. Voltage waveform and superimposed graph of sine function as a function of the sample number

On the basis of the distance between course derived from the measurement of the theoretical course, one can specify the instantaneous angular velocity of the engine crankshaft. The theoretical course (obtained as a result of approximation) is treated as a course characteristic for the engine running without instantaneous angular accelerations ( $\varepsilon = 0$ ). In connection with that shift the real course to the left indicates the negative value of the instantaneous crankshaft angular accelerations ( $\varepsilon < 0$ ), and to the right – the positive value ( $\varepsilon > 0$ ). This principle is shown in Fig.7.

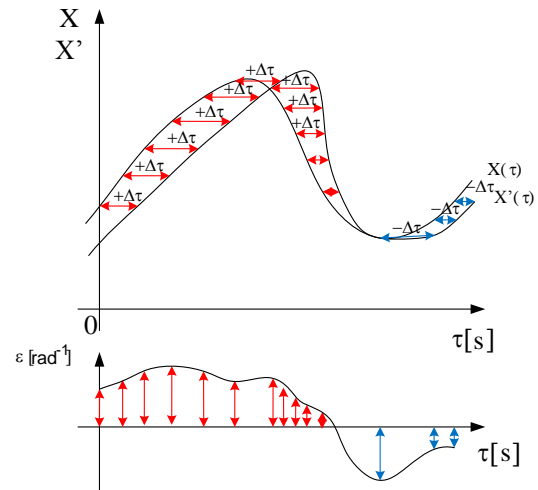


Fig.7. Graphic interpretation of a method for determining the instantaneous angular velocity of the engine crankshaft

The accuracy of the proposed method can be increased in the case of diesel engines driving three-phase synchronous generators. Then it is possible to measure phase-to-phase voltages  $L_1-L_2$ ,  $L_2-L_3$ , and  $L_3-L_1$ . This can be done by measuring phase voltages across all specified phases at a time. (Fig.8).

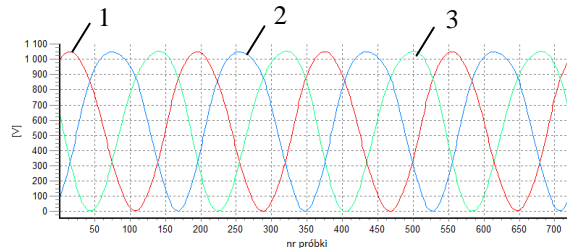


Fig.8. Phase-to-phase voltage of  $L_1-L_2$ ,  $L_2-L_3$ ,  $L_3-L_1$  as a function of the sample number

As a result of the analysis of changes in the instantaneous engine crankshaft angular velocity based on phase-to-phase voltages  $L_1-L_2$ ,  $L_2-L_3$ , and  $L_3-L_1$ , there are obtained three waveforms. Determination the averaged course of instantaneous angular crankshaft speed enables to minimize the effect of random errors.

### 3. Summary

The proposed in the paper method for evaluating the technical condition of selected structural elements of the reciprocating internal engines driving a synchronous generator in the ship power plant, allows them to run against the parametric assessment. This will allow the application to ship auxiliary engines with low diagnostic susceptibility more effective maintenance strategy according to their technical condition. Moreover the advantage of the presented method is a complete lack of interference in the engine structure. The measurement of phase-to-phase voltages or vibration accelerations do not require any modifications within both the

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engine and the generator. In modern marine auxiliary diesel engine constructions will not be required even a reference signal from measurement of injec-

tors vibrations. It is possible to obtain such a signal from the computer controlling the generation set.

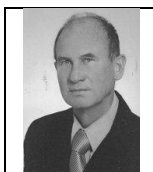
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