ABSTRACT

COMPARATIVE ANALYSIS OF HARMONIC COMPONENTS OF TORSIONAL SHIP DRIVE SYSTEM WITH A RECIPROCATING INTERNAL COMBUSTION ENGINE

The aim of the study was to investigate whether it is possible to diagnose selected damage to a marine reciprocating internal combustion engine, based on a comparative analysis of the harmonic components of the torsional vibrations of the D-E shaft measured with optical sensors.

The work consisted of nine chapters consisting of 67 figures and 53 tables.

The first chapter presents the reasons for using propulsion systems with a reciprocating internal combustion engine in shipbuilding. Based on the literature review, the number of operated drives with this type of engine and the environmental aspect related to their operation were determined. Development trends and their influence on torsional vibrations were also determined.

The second chapter presents the definition of torsional vibrations and their relationship with the barred speed range (BSR) occurring in the operation of low-speed reciprocating engines. The breakdowns caused by torsional vibrations and the applicable standards for the maximum BSR transit time are also presented. The reasons for the measurements of torsional vibrations and the methods of their measurement along with their advantages and disadvantages are given.

In the third chapter, based on the available literature, the status of the issue of using the shaft torsion signal for diagnostic purposes was assessed. The author concluded that:

a) the rotation of the crankshaft carries the information contained in the indicator diagram,
b) if the author's research shows a reaction of the amplitude values of individual harmonic components or fragments of torsional vibration spectra measured with optical sensors to the introduced damage, then their diagnostic usefulness will not be overestimated.

Ultimately, it may be the basis for the use of optical sensors in operational practice for diagnostic purposes (piston engines of small, medium, high and high power), both on conventional and autonomous ships.

Chapter four defines the thesis and scientific hypotheses of the work as well as the purpose of the work:

The aim of the work is to investigate whether it is possible to diagnose selected damage to a marine reciprocating engine, based on a comparative analysis of harmonic components of the torsional vibrations of the D-E shaft measured with optical sensors.

The fifth chapter describes the composition of the test stand, i.e. the research object and the measuring equipment used, with particular emphasis on the research system for measuring torsional vibrations of the shaft based on optical sensors.

Chapter six presents the course of the stand tests as well as the assumptions of the experiment and the research plan. The test plan consisted of six tasks and concerned the measurement of pressures in cylinders, in the fuel injection system and torsional vibrations of the D-E shaft in a fully operational condition and in a partially operational condition - with introduced malfunctions.

The seventh chapter describes the spectra preparation method and specifies the sample sizes. Comparative analyzes of harmonic components of the D-E shaft torsional vibrations in the states of full and partial serviceability were performed on the basis of the classical coefficient of variation.

In the eighth chapter, the feasibility study of parametric and non-parametric statistics of the spectra obtained was made. The spectra of torsional vibrations did not have a normal distribution, therefore, attempts were made to normalize them by means of the transformation with the square root and the decimal logarithm. On the basis of the study, the pro-parametric ANOVA and Dunnett statistics as well as the non-parametric ANOVA of Kruskal-Wallis spectra for D-E were performed in the fully operational condition and in a partially operational condition.

Chapter nine summarizes the general characteristics of the results, cognitive research results, utilitarian research results, and proposed directions for further work. The author came to the conclusion that the obtained research results allow to state that the aim of the work has been achieved. Chapter 6 confirms the thesis contained in subsection 4.2. of this work, which assumed that it is possible to measure the torsional vibrations of the DE shaft on the basis of optical sensors of the modified ETNP-10 Ship Propulsion Control System. Chapters 7 and 8 prove the hypothesis that the harmonic components of the D-E shaft torsional vibrations measured with optical sensors differ from one another depending on the serviceability of the ZSE and contain diagnostic information about the technical condition of the injection and supercharging system components. In subsection 7.2 it was proved that the comparative analysis of the harmonic components of the D-E shaft torsional vibrations measured with optical sensors allows to identify diagnostic symptoms useful in identifying selected damages of elements of the injection and supercharging systems. After the analysis of the obtained sequences of logical parameter differences (d - d_n) values for individual harmonic components of the tested operational states of the D-E engine, it was found that it was possible to identify the engine suitability states by means of a sequence within the frequency range from the first harmonic component (12.5 Hz) up to the fifth order (62.5 Hz). In Tables 7.5 to 7.13, these ranges are shown by bolding the border of the table portion.

The parametric and non-parametric statistical tests performed in Chapter 9 showed the presence and absence of significant statistical differences between the tested samples and the corresponding conditions of state. The best reactions to the introduced inefficiencies were shown by the non-parametric Wilcoxon pair sequence tests performed for the load of 250 kW. It concerned the spectra:

a) harmonic component 6.25 Hz,
b) limited to the 12th order harmonic.

They were able to reveal malfunctions introduced in the injection system. The obtained Z values were different for individual malfunctions.

The obtained results, however, did not provide unequivocal information on the frequency of irregular running of the engine (Table 7.2). At the present stage of research, the exact frequency of these anomalies in particular subsequent cycles of the D-E engine is impossible to detect. Further directions of work are presented in order to detect them and to increase the frequency accuracy of the obtained spectra.

Only one DFT spectrogram based on the Cooley-Tukey algorithm using the Hamming smoothing window was used in the work, it is advisable to check how the spectrum distribution will be affected by the use of other windows.

On the D-E engine, malfunctions were introduced with a noticeable impact on its operating parameters, it is advisable to carry out measurements for malfunctions of various degrees of development in order to determine:

a) minimum threshold values for which it is possible to detect differences in the obtained spectra, e.g. for an injector nozzle,
a) with an increased number of coked injection holes,
b) their influence on the ranges of the obtained values of the test statistics (Z, p),
c) the ranges of the coefficient of variation V_s.
d) determining trends in changes.

The above will be the basis for the development of mathematical models describing the relationship between the development of disability and the diagnostic symptoms indicated in the study.