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THE USE OF THE AUTOMATIC FAULTS CLASSIFICATION METHOD FOR ENGINE FUEL INJECTION SYSTEM DIAGNOSIS

WYKORZYSTANIE AUTOMATYCZNEJ METODY KLASYFIKACJI USZKODZEŃ DO DIAGNOZOWANIA UKŁADU WTRYSKOWEGO SILNIKA SPALINOWEGO.

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***Abstract**: The paper presents the diagnosing possibility of the marine diesel engine fuel injection system. The method is based on an indicator diagram analysis. The algorithm of the faults detection was built with a use of neural networks. The experience data has been collected during the test at the Sulzer 3Al 25/30 engine. The indication diagram has been recorded by the electronic indicator Unitest 201. The paper presents also following stages of a diagnostic research: the diagnostic data acquisition during active experiment, the diagnostic model construction, the automatic classificator construction and the verification. The proposed diagnostic method can be used as an example of the automatic evaluation of the engine technical state.*

***Keywords:** engine fuel injection, diagnostic research*

***Streszczenie:** Tematem publikacji jest określenie możliwości diagnozowania uszkodzeń aparatury wtryskowej silnika okrętowego w oparciu o przebieg wykresu indykatorowego. Algorytm wykrywania uszkodzeń został zbudowany z wykorzystaniem sztucznych sieci neuronowych. W celu weryfikacji algorytmu diagnostycznego przeprowadzono eksperyment czynny na okrętowym silniku spalinowym typu Sulzer 3Al 25/30 w zmiennych warunkach eksploatacji. Dane doświadczalne pozyskano przy pomocy indykatora elektronicznego Unitest 201.*

***Słowa kluczowe:** silnik spalinowy,badania diagnostyczne*

INTRODUCTION

The technical diagnostics plays a very important role during the exploitation of a marine machinery equipment, especially a diesel engine. The complicated structure of the diesel engine causes, that its technical state estimation is very difficult. In such a situation, the automatic faults classification methods are a very useful and helpful tool for a watchkeeping engineer, who is responsible for the proper operation. The practical knowledge about the construction and the working principles of a such diagnostic method should be an important point in a marine engineers education process.

The application of the marine diesel engines is linked with the frequent faults in a fuel injection system. The technical state of this system has an influence on the combustion. The engine performance, its durability and reliability strictly depend on the proper course of a combustion process. On the other hand, the condition of the injection system is linked with the emission of the toxic combustion fumes and the fuel consumption.

The fuel injection system is one of the most breakable part of an engine. The faults in this system does not usually stop the engine, so the engine exploited in a bad technical state has the following features:

- higher fuel consumption
- higher gas and toxic particles emission
- problematic start-up and quicker use of the main tribologic systems of an engine [4].

On the grounds of the analysis of the diagnostic methods, referring to the fuel injection system, it was found that most of them base on the fuel pressure in an injection pipe between a pump and an fuel injector [3, 7]. It does possess some limitations, such as the pressure in the injection pipe is usually inaccessible in the ship engine room (the engine needs to be equipped with some additional sensors and the measuring devices which record the pressure curve).

For this reason, there is a need to work out the algorithm, which would use the other diagnostic signal. Bearing in mind, the fact that this diagnostic method is supposed to be a cheap alternative to other complex diagnostic systems, it has to be a parameter relatively early accessible for measuring and at the same time giving an information about the condition of the fuel injection system.

Because of that, the pressure in a cylinder (measured behind the indicating valve with the use of electronic indicator) was taken as a diagnostic signal.

THE DIAGNOSTIC METHOD OUTLINE

The idea of this method was based on the use of a model of the pressure changes in a cylinder for the fuel injection system technical state diagnosis. This model was used to calculate a standard pressure level for the engine without the faults. After that the residuum signal was calculated with the use of the standard pressure curve and the measured pressure. This signal showed some incompatibility between the nominal (without the faults) and faulty conditions of the fuel injection system. The course of the residuum signal was then analised from the point of view of the fuel injection system technical state. The general structure of the diagnostic algorithm is shown on the figure 1.

The algorithm presented in figure 1 consists of two main blocks: generation and classification of residuum values. The generation block reckons the residuum signal by comparing the signals from the pressure model with the measured values. The reckoned residuum signal should be equal zero while the system is working in the nominal conditions, and in e case of fault, it should be different from zero. The classification block distinguishes the damage in the fuel injection system based on the previously reckoned residuum signal.

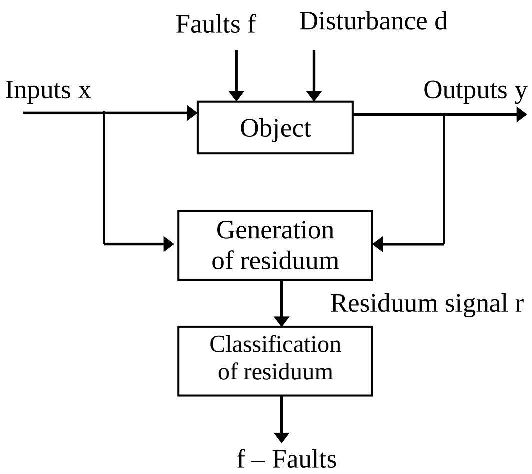

Fig. 1. The general structure of the diagnostic algorithm.

Because of the difficulties in analytic modelling of the complex objects and the processes, the neural networks modelling was used. The neural networks are a perfect tool for the modelling of illinear objects, thanks to such features like the approximation of the optional, constant illinear relations and the ability to learn and adapt. The neural networks are also widely used in the diagnostics [6].

There were used perceptron neural networks with one hidden layer, as well as for modelling the course of pressure in a cylinder as for classifying residuum signals. The error back propagation algorithm was used to teach the network.

At the beginning of research the neural model of pressure course in a cylinder was created. The model showed the curve of standard pressure behind the indicating valve as an engine load function. The load of the engine was estimated from the compression pressure curve. The relation between the compression pressure and

the engine load is typical for a turbocharged engine. The compression pressures in the range of 55-50 crank angle degrees before TDC (top dead centre) were used as an inputs.
Modelling and analyzing was limited to 40 crank angle degrees (10 before TDC and 30 after TDC – fig. 2).

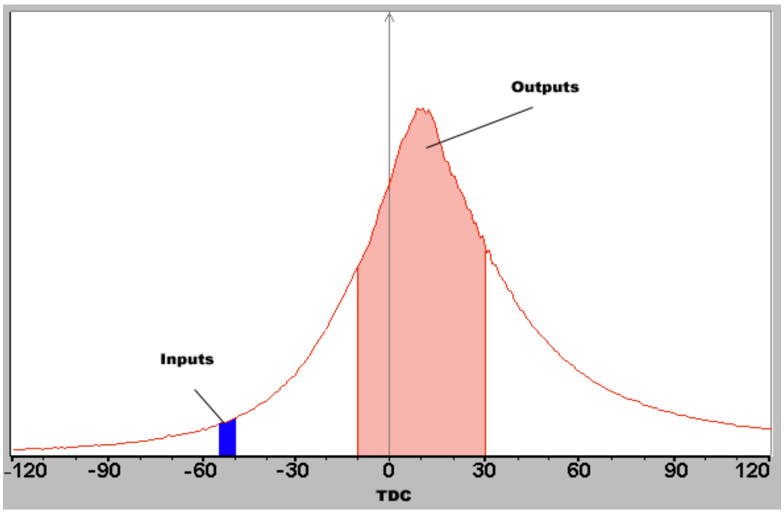

Fig. 2. The range of the inputs and outputs of the neural model of the combustion course.

THE RESEARCH RESULTS

The experimental research was carried out on the four-stroke supercharged marine diesel engine, Sulzer 3A1 25/30 type. The electronic indicator Unitest 201 was used for the engine indication.

In the first part of the research the neural model of pressure course for a nominal state was developed. The model was based on the indicator graphs for the loads from 50 kW to 250 kW. It is possible to calculate an example pressure curve within the range from 10 crank degrees before TDC to 30 crank degrees after TDC. The comparison between the neural model with the real curve of pressure was presented in figure 3.

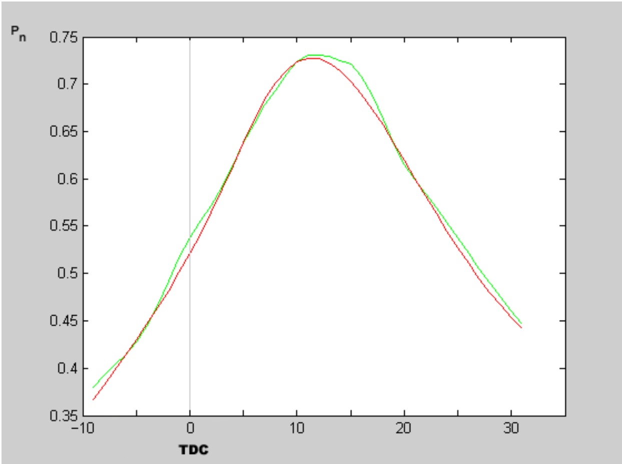

Fig. 3. Example pressure courses: the dashed line-calculated using the model, the continuous line-measured.

The active experiment was carried out to verify the proposed diagnostic method. The following faults of the fuel injection system was simulated during the experiment:

a) the fall of tension of the fuel injector spring,
b) the injection pump wear,
c) the fuel injector nozzles decalibration,
d) the coked fuel injector nozzles.

During experiment, one level of the fault was simulated and then the pressure in the cylinder was measured, within the range of the engine load from 50 to 250 kW. For each simulated engine state 42 pressure curves were registered.
The implementation of the several faults at the same time and various levels of a given faults were not concerned in the experiment.

Table 1. The simulated faults with the symbols.

Symbol	State of engine
K1	nominal state without faults
K2	the fall of tension of the fuel injector spring
K3	the injection pump wear
K4	the fuel injector nozzles decalibration
K5	the coked fuel injector nozzles

The two terms were introduced to verify classificatory neural networks activity; a relative error and a wrong assign error. The relative error defines how many examples from the certain class were wrongly identified.
The wrong assign error defines how many negative examples to the certain class were assigned to it.

The results of the faults classification are presented in table 2.

Table 2. The results of the classification with errors.

Classificatory network	The number of the assigned to class					Relative error	Mean relative error	Wrong assign error	Mean wrong assign error
	K 1	K 2	K 3	K 4	K 5				
K2	2	**38**	4	5	2	10 %	**8 %**	6 %	**4 %**
K3	0	0	**39**	4	1	7 %		2 %	
K4	1	3	8	**37**	2	12 %		7 %	
K5	1	0	2	0	**41**	2 %		1 %	

CONCLUSIONS

1. Using the developed method, it is possible to diagnose (relative error below 10%) such faults like fall of tension of the fuel injector spring, the injection pump wear and the cokes of the fuel injector nozzles. However in a case of the fuel injector nozzles decalibration the observed relative error was about 12%.

2. The low diagnose quality can be caused by:

   a) the errors in the measurement of pressure in a cylinder,
   b) the errors in the representation of the pressure in a cylinder by nominal neural model,
   c) low sensivity of the diagnostic signal to certain fault.

3. The developed diagnostic method can be used in a practice for the automatic, fuel injection system faults classification.

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