Article citation info:
WITKOWSKI, K. The ability to fault detection in the injection system marine diesel engine using chosen method pattern recognition. *Combustion Engines*. 2013, **154**(3), 367-370. ISSN 0138-0346.

Kazimierz WITKOWSKI **PTNSS–2013–SC–036**

The ability to fault detection in the injection system marine diesel engine using chosen method pattern recognition

Abstract: The paper describes the possibility and advisability of using chosen method pattern recognition in the diagnosis injection system of marine diesel engine. It has been shown the desirability of using one of the methods of deterministic pattern recognition, defined as a method of measuring the distance from the pattern. This method belongs to the group "metric recognition methods", which are based on the assumption that the current image of the technical condition of object is close to one of the known symptoms of fault. The current condition of the object is described by a set of diagnostic parameters values and identified faults is also described such sets of parameters. The possibility of using the presented method has been shown to detect faults injection system elements, basing on the results of research the marine diesel engine.

Keywords: *fault detection, pattern recognition, injection system, marine diesel engine*

Możliwość detekcji uszkodzeń układu wtryskowego okrętowego silnika tłokowego z wykorzystaniem wybranej metody rozpoznawania obrazów

Streszczenie: W artykule przeanalizowano możliwości i celowość wykorzystania wybranej metody rozpoznawania obrazów w diagnostyce układu wtryskowego silnika okrętowego. Wykazano celowość wykorzystania jednej z deterministycznych metod rozpoznawania obrazów, definiowanej jako metoda pomiaru odległości od wzorca. Należy ona do grupy metrycznych metod rozpoznawania, które są oparte na założeniu, że aktualny obraz stanu technicznego obiektu opisany wartościami parametrów diagnostycznych jest bliski jednemu ze znanych, typowych objawów uszkodzenia. Bieżący stan obiektu jest opisany przez zbiór wartości parametrów diagnostycznych i znane uszkodzenia również opisuje taki zbiór parametrów o odpowiednich wartościach. Możliwość praktycznego stosowania tej metody w detekcji uszkodzeń elementów układu wtryskowego, wykazano w oparciu o badania przeprowadzone na okrętowym silniku tłokowym.

Słowa kluczowe: *detekcja uszkodzeń, rozpoznawanie obrazów, układ wtryskowy, okrętowy silnik tłokowy*

1. Introduction

Contemporary operating marine power plant requires entering the diagnostic systems on the ships.

They can bring a number of tangible benefits of fuel economy, reduced component wear, lengthening periods between repairs and irrational aimed among other things to improve the safety of navigation.

Marine diesel engines are in the vast majority of main propulsion cargo vessels and are used to propel marine power generators. Their operating costs are very high, mainly due to the ever-increasing cost of fuel and lubricating oils. That's why marine engines operating costs account for over 70% of operating costs across the engine room. A direct relationship between the reliability of marine diesel engine and safety of navigation and the fact that significant share of the operating costs of ships have engines operating costs, make it on ships the overwhelming number of diagnostic methods and diagnostic equipment is developed in for those objects.

Utilitarian purpose of this activity should be able to:

- tasks leading to the identification and determination of the current state, resulting in a diagnosis,
- future technical condition diesel engine recognition, which will result in the genesis
- predict future states of the engine, resulting in a forecast, defined as the time horizon to determine future changes in technical condition.

If possible, you should also link the ability to determine the actual engine condition with the rational planning and perform repair works.

2. Methodology for diagnostic solving tasks

The success and widespread use of diagnostic systems and devices for marine engines depends to a large extent on the improvement of diagnostic algorithms. Still in the construction of such algorithms and diagnostic creating programs is used mostly classical approach, the methodological basis can be reduced to the following tasks:

- assess the impact of demage in the various of the functional device nodes on his work and to change the values of diagnostic parameters, here are used experimental methods, based on real objects or mathematical models,

- determination of diagnostic parameters serviceable object
- choice of diagnostic parameters because of their sensitivity to change of the technical condition of the facility and to minimize their number,
- to develop diagnostic matrix (faults matrix),
- to develop diagnostic algorithm and diagnostic program.

An interesting addition to the classical approach seems to be the use of methods based on the theory of pattern recognition. Here we can distinguish probabilistic and deterministic methods to identify, among other things, described by M.Ajzerman [1] and I.Birger [2].

In the probabilistic approach, it is assumed that there is an object that is in one of *n* random states D_i. It is also known for a set of diagnostic parameters that characterize a given probability of the state of the object. Should formulate principle of taking decisions, at which the diagnosis of selected set of parameter values can be applied to one of the possible diagnoses (states). This method is also very important to assess the reliability of the solve and the degree of risk of erroneous solve.

Deterministic methods to identify diagnostic solved the task using multidimensional geometric space and vector calculus. If the object is described in n-dimensional vector X, is any state of the object is shown in the n-dimensional parameter space as a point, but rather a certain area of the space. You should find the principle that the diagnosed object whose condition is described by the vector X is compared with the corresponding specific area of the diagnosis. The solution to this problem can be found using linear methods, potential functions, stochastic approximation and metric methods recognition.

One metric methods of recognition is diagnose by measuring the distance from the pattern. It is assumed that the current pattern of the object described in the technical diagnostic parameter values is close to one of the known, common symptoms of fault.

It is assumed, that it is possible to distinguish the technical condition of the object based on observations patterns. They are formed of the diagnostic parameters that describe its condition. Diagnostic parameters form n-dimensional state vector X in the symptoms of faults space:

$$X = (x_1, x_2, ..., x_j, ..., x_n) \tag{1}$$

where:
X - vector of the test object,
x_j - coordinates of the symptoms (which may be continuous or discrete quantity).

In n-dimensional space, there are a number of reference vectors Ai, created on the basis of tables (matrix) the faults and describing selected technical object states. Each of them corresponds to the diagnosis D_i:

$$A_i = (a_{i1}, a_{i2}, ..., a_{ij}, ..., a_{in}) \tag{2}$$

Diagnostic measure of the distance between the vector X and the subsequent vectors A_i is expressed in the formula:

$$L_i = l^2 \cdot (X, A) = \sum_1^n \lambda_{ij}^2 \cdot (x_j - a_{in})^2 \tag{3}$$

where:
L_i - diagnostic measure of the distance between the vector X_i and vector A_i,
λ_{ij}- weighting factor j-th dimension of the i-th and diagnosis.

Examination of the state of the object, so that the diagnosis, measures the distance between the end of the vector X, and the ends of the individual vectors A_i and proper analysis of these distances. The shorter the distance between the points in comparison with the other distances, is the higher the probability of faults assigned to the relevant point.

$$L_i = \min \;\Rightarrow\; x \in D_i \tag{4}$$

This analysis comes down (in the simplest case) to designate so-called identify factors ξ_i:

$$\xi_i = \frac{1/L_i}{\sum_{s=1}^{n} 1/L_s} \tag{5}$$

3. Experimental research

3.1. Object of research

The object of the research was ship's diesel engine SULZER AL25/30. View the test stand is shown in Figure 1. The test engine is characterized by the following basic technical data:

- power of a cylinder [kW] 136,
- number of cylinders [-] 3
- rotational speed [r / min] 750,
- mean effective pressure [MPa] 1.575,
- compression ratio [-] 13,
- specific fuel consumption [g / kWh] 204,
- turbocharged - turbocharger BBC VTR160N
- load an electrical generator,
- number of cylinders [-] 3.

3.2. Preparation of test plan

The marine diesel engine is technically complex object. In this case, a significant help in solving diagnostic tasks is to divide the engine into functional systems. So this is an action to decompose an object and diagnosis with decentralized structures. The correctness and effectiveness of this action was confirmed in the work of many authors, including publications J.M. Koscielny [3]. To avoid an arbitrary division, adopted the following procedure.

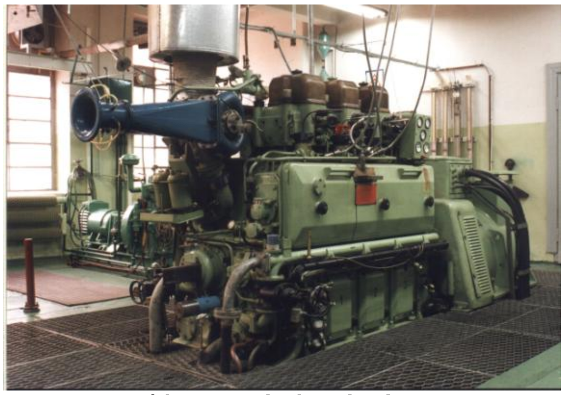

Fig. 1. View of the test stand - ship's diesel engine SULZER AL25/30

Collected statistics data on the frequency of specific faults and data on their potential negative impact on the process of working. This allowed choosing fuel injection for diagnose.

Statistics show that nearly 50% of all failures are the fault of marine fuel injection system, and the most common injury in relation to:

- injectors - 41%
- injection pumps - 38%
- fuel injection pipes - 12%.

For the most fault injectors are:

- wear conical needle - 73%
- wear and coking spray holes - 12%
- springs property loss (pressure drop across the injector opening) - 4%
- other reasons - 11%.

Fault to injection pumps are most often associated with:

- leaking valves - 42%
- precision pair leakage - 24%
- seizing piston - 18%
- other reasons - 16%.

Their diagnosis should choose the right set of diagnostic parameters, according to the following basic criteria:

- informational value, or the amount of information about the condition object that contains the parameter,
- degree of fault location, so as closely related to one specific parameter structure,
- availability and ease of measurement.

3.3. Research plan, research results

Based on the analysis described in section 3.1 developed a plan research. It is assumed that:

- tests will be made on the basis of the active experiment,
- selected typical faults of the injection system will be simulated in such a way as to be as accurate and real failure occurring during operation of the engine,
- tests will be carried out in a wide range of engine load - for a technically sound engine and then simulated defects,
- recorded will be as large a set of parameters which will be selected diagnostic parameters used in the diagnosis.

In the injection system simulated the following faults:

- drop injector opening pressure,
- non-leakproof injection pump (precise pair),
- wear the spray holes,
- carbonization of the spray holes (plugging spray holes).

Our results indicated helped minimize the multiplicity of diagnostic parameters based on:

- calculated sensitivity of each of them to change the engine condition,
- statistical analysis of measurement results.

Ultimately to the fuel injection system diagnosis selected the following parameters:

- maximum cylinder pressure p_{max},
- maximum injection pressure $p_{max\ inj.}$,
- mean indicated pressure p_i,
- air pressure charging p_d,
- exhaust gas temperature T_g.

Based on the obtained experimental data was possible to build a diagnostic table (a diagnostic matrix) - Fault Diagnostic System (FIS), which is shown in Figure 2.

S/F	f_1	f_2	f_3	f_4
s_1	0	+1	+1	+1
s_2	0	-1	+1	-1
s_3	-1	-1	+1	-1
s_4	-1	-1	+1	-1
s_5	0	-1	-1	+1

Fig.2. FIS injection system marine diesel engine
s_1 – air pressure charging,
s_2 – exhaust gas temperature of the cylinder,
s_3 – maximum cylinder pressure,
s_4 – mean indicated pressure,
s_5 – maximum injection pressure,
f_1 – drop injector opening pressure,
f_2 – non-leakproof injection pump (precise pair),
f_3 – wear the spray holes,
f_4 – carbonization the spray holes (plugging spray holes).

But we can not authoritatively say that the diagnosis had to extend for a further faults (previously unrecognized), leaving the overall number of diagnostic signals $S(s_1, s_2, \ldots, s_n)$, whether this fault $F(f_1, f_2, \ldots, f_n)$ could be identified. Then would increase the set of diagnostic signals, by applying to them the right choice of criteria which were mentioned earlier.

Using table (matrix) FIS was constructed a multi-dimensional space symptoms of damage, which introduced state vector on the basis of measurements done on an ongoing basis. According to the detection method discussed earlier is calculated

ξ_i factor, ie the probability of the damage. These actions can be implemented by computer.

4. Conclusions

For the technically complex objects, object decomposition and decentralized diagnosis, assuming a single fault, enables good location of fault.

Making the right choice of diagnostic parameters is one of the most important factors determining the proper operation of the diagnostic algorithm prepared.

For the technically complex objects, a possible large number of diagnostic parameters is also important to minimize the number of diagnostic parameters, as done for diagnostic algorithm was relatively simple but well-recognized faults.

The above-mentioned objectives can be achieved by introducing the concept of diagnostic sensitivity parameter. Greatly facilitates this, making the selection of diagnostic parameters appropriate decisions. Unfortunately, sometimes difficulty to access and measure the diagnostic parameter may be the reason for withdrawal from using in diagnostic algorithm of good, sensitive diagnostically parameter.

The use of trivalent assessment of the residues in the case diagnostics of the injection system marine diesel engine gives very good results - good distinguishability damage.

Presented in this paper the possibility of using simulation test on the real object for the construction of algorithms and diagnostic programs is laborious and expensive method, but giving the opportunity to build for the object unequivocal diagnostic "tool". It is very important that the simulation method use, simulate faithfully as possible the actual faults that occur during engine operation. Tests can be significantly reduced if are based on the statistics faults most common in the type of engines, simulations will be limited only to them.

The possibility of using pattern recognition theory for purposes of diagnosis marine engine seems to be very convenient and reliable means of obtaining information in the form of ξ_i. However it is possible situation when the some diagnoses to obtain similar values ξ_i. This situation represents a "helplessness" diagnostic program. It is possible, especially when the engine is running with unrecognized failure - lack of representation of such a defect in the space of the symptoms.

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Mr Kazimierz Witkowski, DEng. – doctor in the Faculty of Mechanical Engineering at Gdynia Maritime Academy.

Dr inż. Kazimierz Witkowski – doktor na Wydziale Mechanicznym Akademii Morskiej w Gdyni.