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THE CORRECT SELECTION OF DIAGNOSTIC PARAMETERS OF MARINE DIESEL ENGINE AND THEIR MINIMIZATION OF AS A NECESSARY ACTION IN THE FORMATION OF DIAGNOSTIC ALGORITHM

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Abstract

This article describes the methodology of creating algorithms and diagnostic programs. Still in the construction of such algorithms and diagnostic creating programs mostly is used classical approach, the methodological basis can be reduced to the several basic tasks. One of them is the proper selection and minimization of diagnostic parameters. The article shows the importance of proper selection and minimization of diagnostic parameters on the example of the diagnostics of the injection system of a marine diesel engine. It was indicated to practical usefulness for this purpose calculated the values sensitivity of a given parameter. The stronger the diagnostic parameter responds to a change in the structural parameter, the greater its diagnostic sensitivity is and thus the early development of a given fault can be detected based on deviation analysis of this parameter from its reference value. Based on experimental data, FIS (Fault Isolation System) matrix was built after selecting and minimizing diagnostic parameters. Triple-valued evaluation of residues (–1, 0, +1) was used. The research was carried out on a real object – a four-stroke, medium-speed marine engine from Sulzer. The impact of selected fault in the injection system on the diagnostic parameters was researched and a FIS (Fault Isolation System) matrix was built on this basis.

Keywords: *ship diesel engine, diagnostic parameters, diagnostics programs, experimental data, Fault Isolation System*

1. Introduction

Modern marine diesel engines are characterized by complex and complicated construction and high levels of thermal and mechanical loads. Overlap is also specific working conditions, the impact of aggressive of combustion of heavy fuel oil (residual oil) and a number of other factors, which combined can lead to a number of faults. After failure, engine continues to perform its basic working function, but its technical-operational property is worse. If the faults are not diagnosed in time, it can lead to failure to discontinue operation of the vessel, which together lead to serious economic depreciation.

Implementation of the diagnosis to operation of marine engines gives a chance for early detection of possible failures and effectively avoids serious and costly consequences of it.

The success and widespread use of diagnostics systems and devices for marine engines depend to a large extend on the perfection of diagnostic algorithms.

High efficiency is characterized primarily based on the diagnosis of parametric algorithms built on actual experimental research.

Creating algorithms and diagnostic programs should seek to obtain a good distinguishability of faults, which ensures and clarity diagnosis.

2. Create diagnostic system

Very important stage of our work is to understand the relationship between respective faults and the values of diagnostic signals in diagnostics system.

This information may become from modelling studies. There are analytical models, neural and fuzzy [3]. They may be also accomplished by actual experimental research. They can carry out the passive or active experiment. Passive experiment is time consuming, because very often you use the active experiment. Individual faults are then simulated as accurately as possible. The course of active experiment can be significantly reduced by selecting the diagnosis of major motor functional nodes, in which they often occur faults. For this purpose, use of statistical data and knowledge from experts, talking about the frequency of occurrence of faults and linking a particular fault disability with a potential threat to the correct operation of the engine.

So, this is an action to decompose the object and diagnosis in decentralized structures. Correctness and effectiveness of such actions was confirmed in the work of many authors, including [1, 2].

On the significant advantages of a decentralized approach to solve the diagnostic complex technical object is the possibility of the occurrence of an assumption of single failure in particular systems object. The considerably simplifies the diagnosis algorithm, and the stage of collecting data obtained through active experiment, significantly shortens the course of the experiment and its costs.

Making actively experiment with simulated faults allows building a diagnostic matrix and then the algorithm and diagnostic program.

3. Methodology for diagnostic solving tasks

The success and widespread use of diagnostic systems and devices for marine engines depends a large extent on the improvement of diagnostic algorithms. 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:

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

The marine diesel engine is technically complex object. Therefore, in accordance with previous considerations must be made of its decomposition. To avoid an arbitrary division, the following procedure was adopted. Collected statistics data on the frequency of specific faults and data on their potential negative impact on the process of working. This allowed the diagnosis to select appropriate motor functional nodes and the most common faults in them [4, 5].

Eventually selected for the diagnosis of components are turbocharging system and engine fuel injection system.

To their diagnosis, selection of the appropriate set of diagnostic parameters according to the following basic criteria:

- information value, the amount of information about technical condition of the object, which contains a parameter.
- accuracy of location of fault and therefore the closest possible relationship with one specific structure parameter,
- availability and ease of measurements of parameter.

The selection of suitable components and for each of them the right set of diagnostic parameters allowed on testing marine diesel engine, based on the active experiment.

Simulations were performed; with big accuracy obtain a faithful reproduction of the actual faults occurring during the life of the engine [6].

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

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

The concept of sensitivity defines the following relationship:

$$K = \frac{\Delta_D}{\Delta_C}, \tag{1}$$

where:

K – sensitive diagnostic parameter (K-factor),

Δ_D – relative deviation of the diagnostic parameter,

Δ_C – relative deviation of the stricture parameter,

- relative deviation of the diagnostic parameter Δ_D:

$$\Delta_D = \frac{\Delta D}{D}, \tag{2}$$

where:

ΔD – deviation of the diagnostics parameter for the unserviceable engine,

D – diagnostic parameter value for technically serviceable engine,

- relative deviation of the stricture parameter Δ_C:

$$\Delta_C = \frac{\Delta C}{C}, \tag{3}$$

where:

ΔC – deviation of the stricture parameter at a given fault,

C – structure parameter value for technically serviceable engine.

4. Experimental research

4.1. Object of research

The object of the research was ship's diesel engine SULZER AL25/30. View of the test stand is shown in Fig. 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.

4.2. 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. Kościelny [3]. To avoid an arbitrary division, adopted the following procedure.

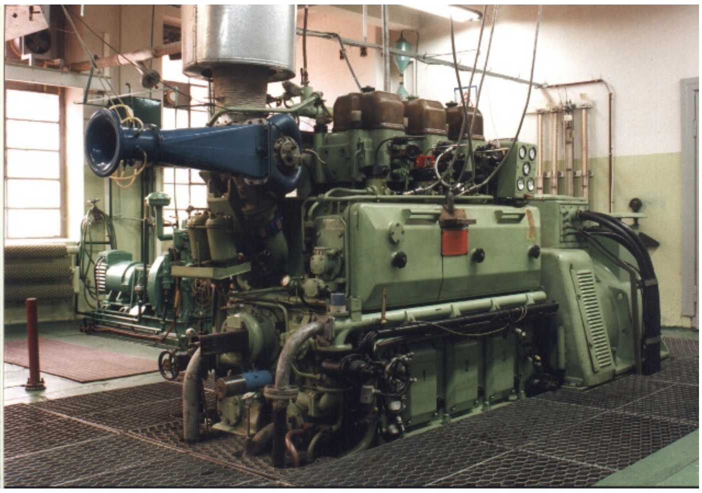

Fig. 1. View of the test stand – ship's diesel engine SULZER AL25/30

Statistics data on the frequency of specific faults and data on their potential negative impact on the process of working were collected. 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 cooking 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.

4.3. Research plan, research results

Based on the analysis described in section 4.2 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-leak-proof 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.

As an example, in Tab. 1 shows the values of the K-factor sensitivity of diagnostic parameters for one of the selected faults in the injection system.

These data refer to the effect on the diagnostic parameters carbonization the spray holes – plugging spray holes of injector (2 holes with 9), and the update a cross-section holes is structure parameter.

The stronger the diagnostic parameter responds to a change in the structural parameter, the greater its diagnostic sensitivity is and thus the early development of a given fault can be detected based on deviation analysis of this parameter from its reference value. Based on the analysis of the K values obtained, an optimum set of diagnostic parameters can be selected to diagnose faults in a given engine system, for example in an injection system.

Based on the calculated values factor K, values calculated for the set of engine parameters during the active experiment, the final selection and minimization of diagnostic parameters for the injection system diagnosis was made.

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 and trivalent residuals assessment, was possible to build a matrix FIS – Fault Isolation System, which is shown in Fig. 2.

Tab. 1. K-factor values – sensitivity of the diagnostic parameters to one of the selected faults in injection system (carbonization the spray holes, plugging spray holes)

Parameter	K-factor values for different engine loads				
	200 kW	220 kW	240 kW	260 kW	280 kW
charge air pressure, p_d	0.34	0.33	0.39	0.38	0.50
turbocharger rotational speed, n_{TS}	0.15	0.30	0.14	0.13	0.26
exhaust gas temperature, T_g	0.27	0.33	0.38	0.38	0.32
mass flow of air through the compressor, m_k	0.25	0.42	0.50	0.55	0.60
indicated specific fuel consumption, g_i	0.15	0.19	0.26	0.16	0.24
excess air ratio, α	0.18	0.14	0.11	0.19	0.24
maximum combustion pressure, p_{max}	0.55	0.54	0.52	0.63	0.47
maximum fuel injection pressure, $p_{max\ inj}$	1.35	2.71	2.13	3.50	2.80
mean indicated pressure, p_i	0.85	0.86	0.79	0.83	0.90

FIS describes the relationship between fault and diagnostic signals and an adaptation of the information system for fault location purposes. The trivalent residue evaluations were used. It is not possible to say that it would be possible to diagnose other damage in the injection system if the selected set of diagnostic parameters S (s1, s2, ..., s5) were not expanded.

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 for the 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-leak-proof injection pump (precise pair), f_3 – wear the spray holes, f_4 – carbonization the spray holes (plugging spray holes)

5. Summary

Making the right choice of diagnostic parameters is one of the most important factors determining the correctness and usefulness of the developed diagnostic algorithms.

With respect to technically complex objects with a large number of diagnostic parameters, it is also important to minimize the number of diagnostic parameters so that the diagnostic algorithm is relatively simple but allowing recognition for damage.

Goals mentioned above can be realized by introducing the concept of diagnostic sensitivity of the parameter. This makes it much easier to make the right decision when choosing diagnostic parameters. Unfortunately, sometimes the difficulty of accessing and measuring the diagnostic parameter can be a reason for not using in diagnostic algorithms of a good, diagnostically sensitive parameter.

The use of trivalent residue evaluations in the injection system marine diesel engine diagnostics, gives very good results – a good distinction of damage.

The possibility of use for the construction of algorithms and diagnostic programs, simulation research on a real object, presented in this article, is a laborious and expensive method, but it is possible to build an unambiguous diagnostic tool for a given object. It is very important that the adopted simulation method accurately reproduce the actual damage occurring during the operation of the engine. Study time can be significantly shortened if; based on the statistics of the most common types of engine damage, only simulations will be limited to them.

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