TOPOLOGICAL MODEL OF APTITUDE OF THE MEASUREMENT CIRCUITS OF MAIN SUBASSEMBLIES OF AN INTERNAL COMBUSTION ENGINE CRANKSHAFT-PISTON ASSEMBLY

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Summary

The paper presents a topological model allowing to determine the probability of aptitude of the diagnosing system (SDG) individual measuring circuits and also to determine to what degree they influence the assessment of the technical condition of an arbitrary main subassembly of crankshaft-piston assemblies as a diagnosed system (SDN).

Keywords: emitted signal F, measuring circuit.

MODEL TOPOLOGICZNY ZDATNOŚCI TORÓW POMIAROWYCH GŁÓWNYCH PODZESPOŁÓW UKŁADÓW KORBOWO-TŁOKOWYCH SILNIKÓW SPALINOWYCH

Streszczenie

W artykule przedstawiony został model topologiczny umożliwiający określenie prawdopodobieństwa zdatności poszczególnych torów pomiarowych systemu diagnozującego (SDG) oraz w jakim stopniu wpływają one na ocenę stanu technicznego dowolnego głównego podzespołu układów korbowo-tłokowych jako systemu diagnozowanego (SDN).

Słowa kluczowe: sygnał emitowany F, tory pomiarowe.

1. INTRODUCTION

Main subassemblies of a marine internal combustion engine crankshaft-piston assembly, in view of their durability, reliability and safety, require constant surveillance by the diagnosing system (SDG). Such systems are being produced by the biggest ship engine manufacturing companies: the German-Danish MAN Diesel company and the Finnish-Swiss Wärtsilä company. However, in the operation practice the same SDGs cannot be used for assessment of the state of different internal combustion engine types. Each engine type without its established diagnosing system should be first subjected to a proper identification procedure and only then the best-fitting diagnosing system can be selected from the existing ones. However, it must be remembered that rational use of engines requires good knowledge of the reliability and durability of the diagnosing systems. The diagnosis is formulated under the assumption that the diagnosing system is in a state of full aptitude. The less the SDG reliability and durability is, the less is the probability that at any time the diagnosing system will be in the state of full aptitude.

This means that probability of formulating a wrong diagnosis is then greater. Therefore, this paper presents a topological model allowing to determine the probability of aptitude of SDG individual measuring circuits and also to determine to what degree they influence the assessment of the technical condition of an arbitrary main subassembly of the crankshaft-piston assemblies (SDN).

2. MEASURING CIRCUITS

In order to perform a measurement [4,8], a measuring circuit must be set up, i.e. a path of signal from the source – friction node where the investigated physical phenomenon occurs – through the processing, comparing and transmitting elements to the output devices for visualizing and archiving the measurement results (Fig.1).

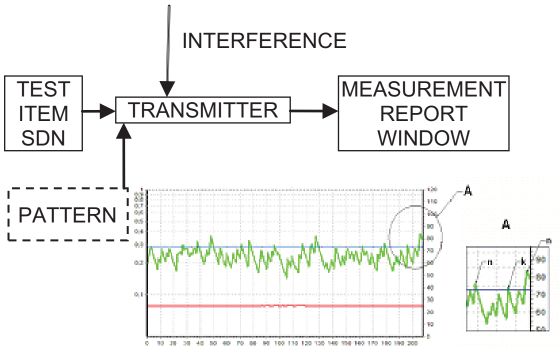

Fig. 1. Diagram of a measuring circuit
where: n - emitted signal amplitudes exceeding the reference level; k - very indistinct amplitudes

Measuring transducer is the measuring circuit basic element performing processing and detection of signals by means of piezoelectric (vibration and pressure) sensors. In other words, the function of those transducers is converting e.g. vibration into a corresponding modulated electric signal. The signal is then prepared for correct conversion into the digital form (e.g. electric charge amplification, removing the electronic noise, galvanic separation). Then the analogue (continuous) signal is changed into digital representation (digital signal) in the A/C converter. This process is carried out in 3 stages: sampling, quantization (digitization) and coding. The obtained digital output signal in the form of digital code is recorded as a bit word. Additionally, at the end the digital signal can be re-converted into voltage analogue signal and displayed. Fig.1 presents an example of measurement report window of the modified T-03 four-ball extreme pressure tester friction node vibration level [3]. The reference level, determined from pattern, defines the surface layer damage due to pitting.

In order to secure proper functioning of all the measuring circuit elements in a given application, the following parameters must be determined: transmission band, measurement range, measurement resolution, measurement sensitivity, measurement accuracy, measurement repeatability, and also the operation conditions (e.g. temperature, corrosion resistance, pressure fluctuations on the transducer etc.).

All the measuring circuit elements should be treated as dynamic objects, therefore all the quantities are time-dependent variables. In the case of disturbances a transitory phase occurs characterised by variability of all the quantities. In effect each measurement result is encumbered with errors of different character and causes. The following errors are distinguished [4,8,9,10,11]:

- measurement static errors resulting from non-ideal characteristics of the measuring elements caused by wrong calibration or by random character effects,
- dynamic errors resulting from the fact that the analogue part of the measuring circuit, the measurement sensor in particular, is not a proportional element (in the dynamic model sense), and also from the fact that digitization is performed at the end of the measuring circuit,
- signal errors: spurious signal caused e.g. by high combustion temperature – so called thermal shock,
- temperature drift caused by temperature fluctuations,
- signal deformations caused by the measuring circuit element connections.

Therefore, after a certain operation time the SDG will not be in a state of full aptitude and the measurement results will not be a sufficiently reliable basis for assessment of the technical condition of a diagnosed main subassembly.

Therefore, the ability of measurement circuit diagnosing must be analysed.

3. RELIABILITY OF DIAGNOSIS

The main subassemblies of a crankshaft-piston assembly are the following: piston with rings and cylinder liner, piston rod with crosshead and, although in a less degree, slide bearings [2]. Safe functioning, particularly during starting the engine, depends on the degree of identification of their real technical condition. Therefore, reliability of the technical condition diagnosis will have an impact on the desired engine operation process. Preparing a reliable diagnosis means identifying the condition of a main subassembly as a diagnosed object (SDN). As SDN characteristics are random variables, estimation of their values is only approximate and the diagnosis of the object technical condition is reliable to a certain degree [5]. In order to estimate the degree of reliability, a multiplexer-based model of many measuring circuits must be constructed allowing to connect in turn many measuring circuits to one measurement system and to obtain precise SDN diagnoses (Fig.2).

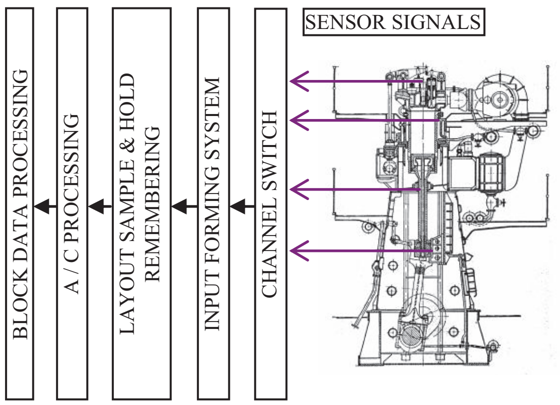

Fig.2. Block model of measuring circuits of the crankshaft-piston assembly main subassemblies

During operation of an engine equipped with SDG the durability of measurement circuit elements must be taken into account, therefore SDG may be divided into the following states of aptitude [5]:

- z_1 – active use state when SDG is in a condition of full aptitude,
- z_2 – active use state when SDG is in a condition of partial aptitude,
- z_3 – active use state when SDG is incapable of identifying the SDN current technical condition,

Therefore, it may be said [5] that probability P_1 is the probability of emitting the F^1 signals meaning the use of SDG during the z_1 state, i.e. $P_1 = P(F^1)$; $F^1=\{z_1\}$. Probability P_2 may be treated as probability of emitting the F^2 signals meaning the use of SDG during the z_2 state, i.e. $P_2 = P(F^2)$; $F^2 = \{z_2\}$.

Probability P_3 may be treated as probability of emitting the F^3 signals meaning the use of SDG during the z_3 state, i.e. $P_3 = P(F^3)$; $F^3 = \{z_3\}$.

4. TOPOLOGICAL MODEL

The topological diagnostic model [1] of measurement circuits of the main subassemblies of an internal combustion engine crankshaft-piston assembly (Fig.3) presents clearly the technical condition – emitted signal relations. Besides, in mapping the set of states of the main crankshaft-piston subassemblies into a set of emitted signals characterizing the states of crankshaft-piston assembly elements, one can use the conditional probabilities that the value of an emitted signal F will change when a certain state s occurs. Making use of the notion of conditional probability, from the same relations a probable conclusion can be drawn that the state s had occurred as the emitted signal F has changed.

The example (Fig.1) of a measurement report window shows that n = 12 emitted signal amplitudes exceeded the reference level, with k = 2 amplitudes very indistinct, which indicates a defect of the measuring circuit. Such observations mean that the signal emitting aptitude probability can be determined [5,6]:

$$P = (n - k)/n = 0{,}83 \tag{1}$$

As the example indicates a significant degree of diagnosis reliability, so it may be intuitively assumed that the measuring circuit is in the z1 state. Then:

$$P = P_1 = p(s_2/F^1) = p(s_2) \tag{2}$$

Additionally, it is also proper to determine to what degree the presented signal emitting capability influences the reliability of assessment of the technical condition of main crankshaft-piston system subassemblies. The T. Bayes axiom on conditional probability [3,7] may be used for the purpose (Table 1).

Table 1: Method of determining the conditional probability

Measuring circuit	1	2		N
„n”	n_1	n_2		n_N
„k”	n_2	k_2		k_N
$P_1 = P(F^1)$	$\frac{n_1 - k_1}{\sum_{l=1}^{N}(n_i - k_i)}$	$\frac{n_2 - k_2}{\sum_{i=1}^{N}(n_i - k_i)}$		$\frac{n_N - k_N}{\sum_{i=1}^{N}(n_i - k_i)}$
$P_1 = P(F^1/s_2)$	$\frac{P(F_1^1)\cdot P(s_2/F_1^1)}{\sum_{i=1}^{N} P(F_i^1)\cdot P(s_2/F_i^1)}$	$\frac{P(F_2^1)\cdot P(s_2/F_2^1)}{\sum_{i=1}^{N} P(F_i^1)\cdot P(s_2/F_i^1)}$		$\frac{P(F_N^1)\cdot P(s_2/F_N^1)}{\sum_{i=1}^{N} P(F_i^1)\cdot P(s_2/F_i^1)}$

The probability $P(F^1/s_2)$ may be treated as the value of probability indicating to what degree a given measuring circuit can assess the technical condition of a diagnosed main crankshaft-piston subassembly.

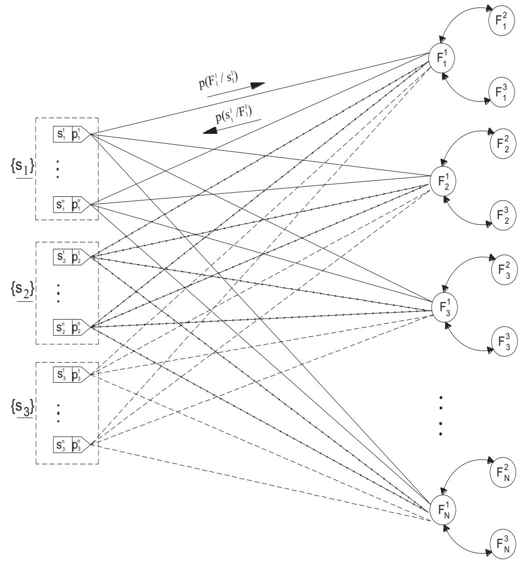

Fig.3. Topological diagnostic model of measurement circuits, where: $F_1^1, F_2^1, \ldots, F_N^1$ – signals emitted from piezoelectric measuring transducers about z_1 aptitude; $F_1^2, F_2^2, \ldots, F_N^2$ - signals emitted from piezoelectric measuring transducers about z_2 aptitude; $F_1^3, \ldots, F_N^3$ - signals emitted from piezoelectric measuring transducers about z_3 aptitude; $\{s_1\}$ state of full aptitude of a main subassembly of engine crankshaft piston assembly; $\{s_2\}$ – state of partial aptitude; $\{s_3\}$ – state of inaptitude; $p(F_1^1/s_1)$ – probability that emitted signal F_1^1 is observed on the condition that state s_1 occurs; $p(s_1/F_1^1)$ - probability that state s_1 occurs on the condition that emitted signal F_1^1 is observed.

5. CONCLUSIONS

The paper presents methods of determining conditional probabilities of aptitude of the measuring circuits diagnosing the technical condition of main subassemblies of a compression-ignition engine crankshaft-piston assembly.

As the measuring circuit wear and tear process progresses, the amplitudes of emitted signal with indistinctly exceeded reference level ”k” increase, i.e. the $P(F^1/s_2)$ value decreases. Therefore, it is recommended to establish a limit level, which, when exceeded, would indicate that the measuring circuit requires repair.

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