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DETERMINATION OF ELEMENTS RELIABILITY FOR POWER PLANTS BASED ON INTERNAL COMBUSTION ENGINES BY LOWEST RESIDUAL ENTROPY METHOD

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The selection technique of diagnostic parameters for the creation of fault detection system of autonomous electric power sources based on gasoline and diesel engines is given in the paper. An analysis of the design features for autonomous electric power sources based on internal combustion engines, which are the most common on the Ukrainian market, was carried out. Thanks to this, a logical model of the research object, which establishes the relation between the main structural elements of the system and determines the possible states of the system, was developed. The effect of fault state initiation for each element on the other system elements was analyzed. An informative criterion – Shannon information entropy is proposed to determine the finite number of diagnostic parameters among the infinite number of possible combinations for physical parameters that characterize the system. The equal-probable cases of exit from operational state of each system elements are considered. The residual entropies of the system at the fault state for one of the autonomous power sources assembly are determined, having applied the concept of Shannon information entropy. The residual entropy value is the informative criterion. The application of this criterion allowed to determine the system elements that most effectively reduce the system uncertainty degree. Based on the residual entropy values, the system assemblies, the state of which should be primarily monitored by diagnostic system, are selected. The diagnostic parameters are determined for such elements, and the ways to obtain them are given.

Keywords*: diagnostic system, electric power source, internal combustion engine, generator.*

Introduction

The modern stage of power-engineering development is characterized by wide application of alternative and renewable power sources. However, the systems used to generate electricity are mostly complex in structure, and the energy itself has a high specific cost. The availability of renewable power sources allows them to be used as self-contained, but the efficiency and reliability are completely dependent on circadian rhythms and the season. In addition, the application possibility of alternative power supplies as reliable autonomous electric power sources is significantly limited, precisely because of the specified features [1, 2]. The availability of a reliable standby electric power source at a modern plant is a guarantee of safe and high-quality operation.

A solution that allows to ensure a backup power supply for enterprises is the use of rechargeable batteries, in particular, based on Li-ion assemblies and generators based on internal combustion engines. The use of the former is significantly limited due to the cost of the required capacity of the rechargeable batteries to ensure enterprise operation. Power plants based on an internal combustion engine remain a simpler and more capital-intensive solution for reserving power sources. We believe that the fact this equipment type is used to generate electrical power by military and ship power plants is evidence of its highest reliability and safety among possible options for autonomous power supply [3–5].

Usage of the standby power source depends on the reliability of the main power supply system and can vary from single starts on year to daily use. The equipment readiness is reduced appreciably, both in the first case due to intensive wear, and in the second case due to intensive ageing of system polymer elements, and deterioration of fuel and lubricants, the consequences of which are deposits in the power supply channels of the internal combustion engine, the rotor demagnetization, etc. These processes, which take place in autonomous power sources based on internal combustion engines, require the constant monitoring to have the possibility for this equipment to be used as the standby power source. The state of backup power supply, in particular the generator motor [6, 7], is particularly important for preventing the occurrence of emergency situations at nuclear power plants. This problem can be solved thanks to the development of a diagnostic system of autonomous power sources based on internal combustion engines.

Let us add that when establishing the technical condition of autonomous energy sources based on internal combustion engines, researchers, depending on their field of activity, pay attention to the mechanical or electromechanical object part [8–10]. However, considering only the object part, possible states and diagnostic indicators are identified, which, of course, can determine the state of only a single component. Thus, in order to find out the object condition as a whole, it is necessary to conduct a whole set of checks for individual elements, which significantly increases the time and cost of diagnosis. It is possible to minimize the costs of this process by considering the object as a whole with the definition of its structure, possible states, and necessary checks.

Purpose and problems of the paper

The research purpose is to develop a new system of technical diagnostics from the determination of the main diagnostic structural elements and states of autonomous power sources based on internal combustion engines, taking into account the interaction of electromechanical and mechanical components.

For the goal attainment, the following problems were solved in the paper:

– to develop a structural scheme of power sources based on internal combustion engines taking into account interaction features of electromechanical and mechanical components, that will allow to establish reciprocal influences of various parts for research object on its state;

– to determine the possible states for autonomous power sources based on internal combustion engines;

– to establish the necessary checks to determine the state of autonomous power sources based on internal combustion engines.

Research results

A typical design that has found the greatest application on power plants and private households is considered in the development of structural scheme for the autonomous electric power source based on a diesel engine. The prototype of most stations on the Ukrainian market are Honda gasoline generators with 2.5–5.0 kW capacity, Hyundai and Forte diesel generators with 2.5–5.5 kW capacity. The line of gasoline generators uses a four-stroke internal combustion engine with air cooling from 163 to 408 cm^3. A feature of this engine type is the lack of a pressure lubrication system – the lubrication is done by spraying. The P19 series float carburetor is used in the fuel system. Most diesel generators have the «Common rail» fuel system. The gas-distribution system includes the lateral two-valve control with lower camshaft and constant phases. A synchronous electric generator with an automatic voltage regulator, which contains rotor and stator windings, is used as an alternator in most generators. The rotor speed of the electric generator is maintained by a centrifugal speed regulator, which connected to the carburetor. There are different variations in the layout of single assemblies. For example, the engine design allows the conversion of the fuel system to a mixed system: fuel and gas. The engine start system can also be different: manual, electric or combined start. An electronic circuit with the flywheel magnet is used as the ignition system. It is possible to complete the automatic start unit, as the main purpose of these autonomous sources is a standby electric power supply.

A logical model of gasoline and diesel generators, which was derived from the operation analysis of autonomous electric power sources based on internal combustion engines, has been developed. Attention should be paid to the mutual influence of the engine and alternating-current generator assemblies from among the structures of logical models, which confirms the need to consider the system as a whole.

So as to the diagnostic system to work with maximum efficiency, in each case it is necessary to solve the problem of choosing the minimum sufficient number of diagnostic parameters [11]. An informative criterion is one of the main criteria for choosing the diagnostic parameter of the system among the possible physical parameters, that characterize the technical state. The diagnostic parameter selected by informative criterion allows to determine the state of the object under research with the highest probability.

Gasoline generator model

To select the diagnostic parameters, we use the block diagram of the gasoline generator (Fig. 1). The system under consideration consists of N=16 elements. For possible states, we take each element failure. We control the state of the autonomous supply by the number of parameters equal to the number of elements k=16. It should be noted that in the general case, each of the elements may have several diagnostic parameters. States table was created as a result of system elements failures research (Table 1).

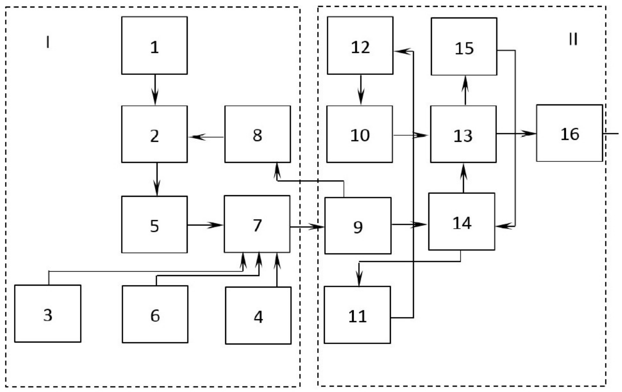

Fig. 1. Logical model of gasoline generator:
I – Gasoline engine; II – Alternating-current generator; 1 – tank; 2 – carburetor; 3 – ignition system; 4 – start-up system; 5 – gas-distribution system; 6 – engine lubrication system; 7 – cylinder-piston group; 8 – speed regulator; 9 – rotor iron; 10 – rotor windings; 11 – contact rings; 12 – brush assembly; 13 – main and additional stator windings; 14 – excitation winding; 15 – automatic voltage regulator; 16 – conductors

The probability of each element failures will be equal to

$$P(S_i) = \frac{1}{N} = \frac{1}{16}. \qquad (1)$$

In this case, the system entropy with finite number of states is maximum.

The initial system entropy is determined by number of possible states

$$H(S_i) = \sum_{i=1}^{n} P(N_i)\log_2 P(N_i) = -16\frac{1}{16}\log_2\frac{1}{16} = 4\,[\text{bit}]. \qquad (2)$$

We denote by m_1 the number of ones in each table row, m_0 the number of zeros in the same table row. The residual uncertainty when performing control of each parameter in the first step is calculated by the formula

Table 1. Gasoline generator states table

Z_k	States																$H(A/Z_k)$
	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	A_{11}	A_{12}	A_{13}	A_{14}	A_{15}	A_{16}	
1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3.662
2	0	0	1	0	0	0	0	0	0	1	1	1	1	1	1	1	3.000
3	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	3.662
4	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	3.662
5	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	3.011
6	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	3.662
7	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	3.011
8	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	3.011
9	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	3.011
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3.662
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3.662
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3.662
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3.662
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3.662
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3.662
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	∞

$$H\left(\frac{A}{Z_k}\right)=\frac{m_1}{N}\log_2 m_1+\frac{m_0}{N}\log_2 m_0 . \qquad (3)$$

The calculation results of the residual entropy are given in the last column of Table 1. The system entropy diagram is constructed on the basis of calculations (Fig. 2), which sets the informative value of diagnostic parameter.

The system element with the lowest residual entropy provides the most of information about its state. Z_2 will be this parameter in the first step, that is, this number corresponds to the carburetor, based on the structural diagram of the alternative electric power source based on the internal combustion engine (see Fig. 1). Z_5, Z_7, Z_8, Z_9 are the following elements that significantly affect the system entropy. These numbers correspond to the gas-distribution system, cylinder-piston group, speed regulator and rotor iron.

It is necessary to operate with physical quantities (the value of system diagnostic parameters) for diagnostic system operation. So, we note the following.

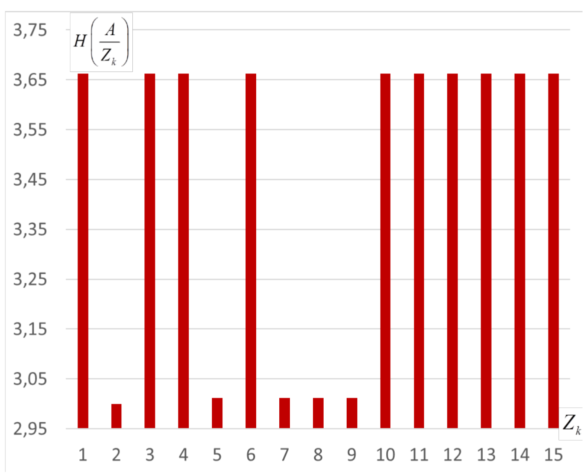

Fig. 2. Gasoline generator entropy diagram

The carburetor state can be determined by fuel presence in the cylinder and by exhausts on compressor mode. The operation of the gas-distribution system and the cylinder-piston group can be assessed by magnitude of the starter current when the engine is running on compressor mode. The operability of the speed regulator can be assessed by analysis of the generated voltage curve. The main reason for the rotor iron fault is its demagnetization. The diagnostic parameter of the lack or low value for the magnetic field strength is the voltage low value on the stator windings.

Diesel generator model

We use a similar approach to determine the diesel generator parameters (Fig. 3). The diesel generator system consists of N=16 elements. For possible states, we take each element failure. We control the state of the autonomous supply by the number of parameters equal to the number of elements k=16. The system states in case of each element failure are summarized to Table 2.

The probability of each element failures will be equal to

$$P(S_i)=\frac{1}{N}=\frac{1}{16} . \qquad (4)$$

In this case, the system entropy with finite number of states is maximum.

The initial system entropy is determined by number of possible states

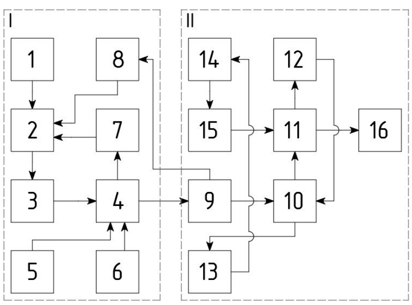

Fig. 3. Logical model of diesel generator:
I – Diesel engine; II – Synchronous generator; 1 – tank; 2 – high-pressure pump; 3 – injector; 4 – connecting rod-piston group with crankshaft; 5 – starter; 6 – engine lubrication system; 7 – gas-distribution system; 8 – speed regulator; 9 – rotor iron; 10 – rotor windings; 11 – contact rings; 12 – brush assembly; 13 – main and additional stator windings; 14 – excitation winding; 15 – automatic voltage regulator; 16 – conductors

$$H(S_i)=\sum_{i=1}^{n}P(N_i)\log_2 P(N_i)=-16\frac{1}{16}\log_2\frac{1}{16}=4\,[\text{bit}] \qquad (5)$$

We denote by m_1 – the number of ones in each table row, m_0 – the number of zeros in the same table row. The residual uncertainty when performing control of each parameter in the first step is calculated by the formula (3).

The calculation results of the residual entropy are given in the last column of Table 2. The system entropy diagram is constructed on the basis of calculations (Fig. 4), which sets the informative value of diagnostic parameter.

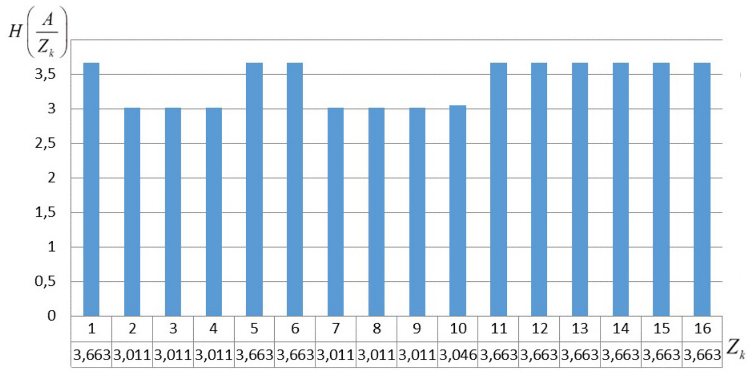

Fig. 4. Diesel generator entropy diagram

In this case, the system element with the lowest residual entropy also provides the most information about its state, and therefore it should be controlled first. Z_{10} will be this parameter in the first step. This number corresponds to the rotor windings based on the structural diagram of the diesel generator (Fig. 3). Z_2, Z_3, Z_4, Z_7, Z_8, Z_9 are the following elements that significantly affect the system entropy. These numbers correspond to the high-pressure pump, injector, connecting rod-piston group with crankshaft, gas-distribution system, speed regulator and rotor iron.

It is necessary to operate with physical quantities (the value of system diagnostic parameters) for diagnostic system operation. So, we note the following.

The state of high-pressure fuel pump can be assessed by fuel pressure value in the mainline. The injectors state can be assessed by correction factors value of the fuel supply through the injectors. The operation of the gas-distribution system and the connecting rod-piston group can be assessed by magnitude of the starter current when the engine is running on compressor mode. The operability of the speed regulator can be assessed by analysis of the generated voltage curve. The main reason for the rotor iron fault is its demagnetization. The diagnostic parameter of the lack or low value for the magnetic field strength is the voltage low value on the stator windings. The rotor windings state can be assessed by each section resistance.

Table 2. Diesel generator states table

Z_k	States																$H(A/Z_k)$
	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	A_{11}	A_{12}	A_{13}	A_{14}	A_{15}	A_{16}	
1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3.663
2	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	3.011
3	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	3.011
4	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	3.011
5	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	3.663
6	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	3.663
7	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	3.011
8	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	3.011
9	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	3.011
10	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	3.046
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3.663
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3.663
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3.663
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3.663
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3.663
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.663

Conclusions

1. The structural schemes of typical constructions for autonomous electric power sources based on internal combustion engines (gasoline and diesel generators) are developed in the paper.

2. The table of system possible states at one assembly fault is compiled. Assuming an equal-probable initiation of system element failures, those that have the greatest effect on the system state uncertainty are

identified. Their state should be determined primarily when the system of technical diagnostics is created. For the gasoline generator these are the carburetor, gas-distribution system, cylinder-piston group, speed regulator, rotor iron. The rotor windings, high-pressure pump, injector, connecting rod-piston group with crankshaft, gas-distribution system, speed regulator and rotor iron are diesel generator elements. Yet the number of such elements can be increased for unmanned diagnostics.

3. The diagnostic parameters and methods of their determination for the fault detection of above-listed system elements are proposed.

4. For systems with feedback, the application of this method leads to uncertainty among the closed elements, because the faulty element signal affects the other elements.

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Визначення надійності елементів електростанцій на базі двигунів внутрішнього згоряння методом найменшої залишкової ентропії

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У роботі представлено методику вибору діагностичних параметрів для створення системи діагностування автономних джерел електричної енергії на базі бензинового й дизельного двигунів. Проведено аналіз конструктивних особливостей найпоширеніших на ринку України резервних джерел електричної енергії на базі двигунів внутрішнього згорання. Завдяки цьому розроблено логічну модель об'єкта дослідження, що встановлює взаємозв'язок між основними структурними елементами системи, а також визначає можливі стани системи. Проаналізовано вплив виникнення несправного стану кожного елементу на решту елементів системи. Серед нескінченної кількості можливих комбінацій фізичних параметрів, що характеризують систему, для визначення кінцевої кількості діагностичних параметрів запропоновано інформативний критерій – інформаційну ентропію К. Шеннона. Розглянуто рівно вірогідні випадки виходу з робочого стану кожного з елементів системи. Застосовуючи поняття інформаційної ентропії Шеннона, визначено залишкові ентропії системи при несправному стані одного з вузлів автономного джерела живлення. Критерієм інформативності є величина залишкової ентропії. Використання даного критерію дозволило встановити елементи системи, які з найбільшою ефективністю знижують ступінь невизначеності системи. На основі величин залишкової ентропії вибрані вузли системи, стан яких має першочергово контролюватися системою діагностування. Для таких елементів визначені діагностичні параметри і наведені способи їх отримання.

Ключові слова*: система діагностування, джерело електричної енергії, двигун внутрішнього згорання, генератор.*

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