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doi:10.15199/48.2023.12.67

Selection of operating parameters in technical equipment diagnostics using vehicle testing as an illustrative example

***Abstract**. Diagnosis of technical equipment is a key area of science and technology in the modern world. It is essential when equipment is repaired by humans, and optimised diagnostics is the basis for the design of self-diagnosis systems not operated by humans. The aim of this paper is to synthesise the topic of the selection of operating parameters during fault finding. Experimental material from automotive service centres was collected and conclusions have been developed.*

***Streszczenie.** Diagnostyka urządzeń technicznych jest kluczową dziedziną nauki i techniki we współczesnym świecie. Jest niezbędna podczas naprawy urządzeń przez człowieka, a także zoptymalizowana diagnostyka jest podstawą projektowania systemów samodiagnozy, nie obsługiwanych przez człowieka. Celem pracy jest synteza tematu wyboru parametrów eksploatacyjnych podczas poszukiwania usterek. Zebrano materiał doświadczalny z serwisów samochodowych i opracowano wnioski. (**Wybór parametrów eksploatacyjnych w diagnostyce urządzeń technicznych na przykładzie diagnostyki pojazdów**.*

Keywords: automotive problem solving, technical device diagnostics, diagnostic methods.
Słowa kluczowe: rozwiązywanie problemów motoryzacyjnych, diagnostyka urządzeń technicznych, metody diagnostyczne.

Introduction

With the rapid development of electronic systems in technical equipment, the problems of finding faults are increasing. Diagnosis is an important step in the repair process of technical objects. The interconnection of different functional systems in a single object, using communication networks, creates problems in diagnosis, because we are dealing with complex relationships that are not fully understood during the design of the equipment. In addition, dependencies arise when faults occur. One of the decisive factors for optimal diagnosis is the selection of current parameters. Access to these parameters is direct by means of measuring instruments and also indirect through installed controllers. This article presents the problems of parameter selection, test methodology and conclusions. The study was carried out taking into account the selection of operating parameters when performing diagnostics and the impact of this selection on the diagnostic results [1, 2].

Problems associated with the choice of operating parameters when carrying out diagnostics

Several aspects of relevance during diagnostics related to the choice of operating parameters can be distinguished, namely:

- several hundred parameters accessible from the controllers;
- ambiguous and imprecise description of parameters in diagnostic scanners;
- incorrect self-diagnosis performed by the controllers, suggesting a fault in another component;
- dispersion of fault information carried over communication networks;
- duplication of fault codes by several or more controllers;
- creation of new relationships between functional systems during a fault, making fault finding difficult;
- difficulty in accessing suspected faulty components, requiring disassembly of other components.

Partitioning of parameters

One hundred to several thousand technical parameters are available in automotive diagnostics. When searching for a fault, the diagnostician classifies and selects the parameters. For the purpose of testing, the parameters are divided into groups. These include current parameters, those calculated by programmes in the controllers, indirect and direct parameters. The classification of technical parameters made it possible to analyse how the diagnostician selects the parameters and to describe them in the form of parameter selection keys. The study results of this analysis are presented in this paper [3, 4].

The operating parameters accessible from the diagnostic scanner are divided according to the way the data are obtained and the period of time when a specific condition of the object occurs.

Partitioning by means of data acquisition:

- obtained directly from sensors connected to communication networks;
- obtained from the controllers to which the sensors are connected;
- calculated by the controllers, based on data from multiple sensors.
- partition related to the time of occurrence of a particular state of an object:
- historical, these are parameter values stored in the controller;
- current, these are parameter values currently being read out;
- future, these are parameter values projected into the future.

Performance parameters measured directly with measuring instruments can be divided according to their characteristics, namely:

- electrical, for example voltage, current, frequency, signal shape;
- mechanical, such as stress, torque, pressure of the medium, among others;
- chemical, where an example is the chemical composition of a fluid;
- physical, for example light intensity or vehicle speed.

In addition to the aforementioned, we also distinguish between performance parameters derived from human observation and feeling. Using one's senses it is possible to assess and interpret technical parameters. Exact parameter values may not be possible to provide, but even an approximate evaluation, often subjective, is of great importance in diagnostics. By assessing the values of the parameters, there is guidance in the selection of measuring instruments and objects to be tested. Examples of such parameters are part vibration, colour change, sounds, odours. Before a diagnostician takes measurements, a decision must be made which objects will be tested and with which instruments. During this assessment, the diagnostician uses observation, experience and intuition to analyse the symptoms of the fault. An example is the testing of the temperature of objects. Temperature is an operating parameter that is important in detecting many faults. During pyrometer diagnostics, not all, but selected components are tested. In the case of abnormal faults, those objects whose temperature change is relevant to the detection of the fault are often overlooked. On the other hand, a diagnostician through observation and sensation, is able to draw attention to precisely these objects and proceed to the relevant measurements leading to the finding of damage [5].

Calculated operating parameters

The operating parameters are recalculated in the controller on the basis of data obtained from a number of sensors. The degree of reliability of the calculated performance parameters is determined by the nature of the parameter in question and the calculation program used in the controller. For example, the calculated adaptation values of the oxygen sensors have a high degree of reliability because they are based on a simple mathematical conversion of the results obtained from the operation of these probes. The method of conversion by different car companies is very similar. Another parameter, such as instantaneous power is calculated in many different ways, so the evaluation of the value of such a parameter should be preceded by an analysis of the conversion method used in a given car model. The reliability of the calculated parameters depends, among other things, on the sensors used by the program during the calculation. If only one sensor is used, which may turn out to be faulty, the reliability of such a parameter is low. Therefore, uncritical use of the values calculated by the controllers may lead to incorrect diagnostics [6].

Methodology and results of the study

The tests were carried out at the SAHIB car service station, which specialises in repairing difficult cases in the detection of faults. Firstly, the results of a preliminary diagnosis carried out with a diagnostic scanner and simple measurements were recorded. If these steps correctly indicated a fault, such a case was discarded. The study dealt with cases where the initial diagnosis proved to be wrong or inconclusive. An inconclusive diagnosis is one where the self-diagnosis results in several fault codes suggesting damage at several locations, or no fault at all despite the apparent failure of the system in questions. In such cases, diagnostic steps requiring specialised measuring instruments and technical documentation must be taken. It is then that a decision is made as to which operating parameters the diagnostician will deal with. The paper presents diagnostic results on three different functional systems.

The results presented are for the diagnostics of the following cars:

58 times Ford Mondeo MK IV cars;
65 times cars Ford Mondeo MK V;
106 times cars Opel Astra J;
24 times cars Opel Astra K;
42 times cars Volvo V50.

The diagnostic work used included Launch and Snapon car scanners, DeltaTech oscilloscope, Draper manometers, Protec and UNIT multimeters. The values given in the tables are averages obtained from several hundred tests on the cars listed above.

Suction manifold air path diagnosis

This paper does not examine the diagnostic methods used, but focuses on the selection of operating parameters during diagnosis, regardless of the type of diagnostic method used. The choice of parameters was dictated by various aspects such as the experience of the diagnostician, the possession of specialised measuring equipment and the possibility of substituting (fitting) components suspected of malfunctioning.

A case report on engine intake air path diagnostics is presented in Table 1. The report concerns the second phase of diagnostics. The first phase of diagnostics involves reading fault codes and taking initial measurements. The second phase involves selecting operating parameters, taking measurements and carrying out analysis.

Diagnostics of the car locking control and electric window lifters

Lock control in the car relates to the comfort electronics. This system is related to the window lifters, and the most common configuration of this system is the controllers fitted to each door and connected to the comfort module. Each control unit has a self-diagnosis programme and records the faults detected in the form of fault codes. Once these codes have been read, measurements are taken with an oscilloscope and multimeter in a specific area of the car. At this stage, the diagnostician only analyses a few parameters to detect the faults (Table 2).

Table 2. Car locking control and electric window lifts diagnostic report

Number of codes registered by the comfort module	Number of parameters read in the first diagnostic approach	Number of parameters read in the second diagnostic approach
0-2	18	2
More than 2	21	3

Table 1. Suction air path diagnostic report

Description of the diagnostic cases studied	Number of parameters analysed during the second phase diagnostics	Operating parameters that contributed to the fault finding	Proven damages
No error codes	16	1. Air intake manifold vacuum measured simultaneously at two different locations; 2. Engine speed; 3. Accelerator pedal position; 5. Engine coolant temperature; 4. The load of the running engine, as calculated by the controller; 5. Exhaust gas composition from the oxygen sensor in the exhaust system; 6. Adaptation values from the oxygen sensor.	1. Intake system leak in 39% of cases; 2. Flow meter in 29% of cases; 3. Vacuum sensor in 25% of cases; 4. Engine malfunction in 4% of cases; 5. Other damage in 3% of cases.
One error relating to the flow meter, intake manifold vacuum sensor, or EGR valve	8		
More than one fault detected by the engine self-diagnosis system	12		

Generalised diagnosis of different functional systems

On the basis of the conducted statistics of the diagnostic work of the various functional systems in cars, a generalised analysis of the number of current parameters needed to detect faults was carried out. Due to the interconnection of the communication networks of the various functional systems, the parameters needed to determine faults are available not only in the system under investigation, but also in other functional systems. Reading of these current parameters is possible via controllers and connected meters directly to the selected components. In this way, several to several hundred parameters can be read and analysed.

The study analysed the diagnostics of various functional systems such as engine control, automatic transmission control, suspension control, comfort electronics, the air conditioning system, as well as the lighting and navigation system (Table 3).

Table 3. Diagnostic report of various functional systems

Number of functional systems where there were error codes	Number of parameters read in the first diagnostic approach	Number of parameters taken into account in the second diagnostic approach	Number of parameters to be analysed to determine faults
1	22	12	8
2	38	18	12
3	45	25	15

In the first approach, the parameters logically associated with the stored fault were read and analysed. This analysis consisted of estimating the values of the current and required parameters in order to find the anomaly. Following this analysis, parameters were selected that raised doubts about the indicated values, or could point to a fault finding. This second analysis requires experience, as well as the connection of additional measuring equipment. At this stage, the values of the current parameters and those calculated by the controller are analysed. Values presented in the form of numbers and also in the form of graphs are examined. The presentation of parameter values in the form of graphs, allows the graphs to be superimposed on each other, or arranged in the form of columns. These methods make it easier to carry out diagnostics by spotting different types of abnormalities. With each successive step in the diagnostics, the number of analysed parameters was reduced. Once faults were detected, the parameters that were needed to detect the damage were determined.

Performance relationships in diagnostic functions

In this section, we will discuss the ordering of parameters during diagnostic work and the derivation of a diagnostic function, based on a preliminary analysis of the read parameters.

The diagnostic processes vary depending on the type of fault, the diagnostic method used, the equipment available and the knowledge and experience of the diagnostician. Despite this diversity, it is possible to distinguish general stages that are repeated in every diagnostic. By analysing several hundred methods of car diagnostics, it has been possible to identify stages that are clearly outlined and outline the diagnostic plan. Five steps were identified, forming the entire diagnostic process:

- initial collection of damage symptoms, operating data and parameters obtained from the diagnostic scanner;
- evaluation and selection of parameters for further analysis if no fault was found in the first step;
- introduction of a function to analyse selected operating parameters;
- selection and application of a method for further diagnostic work such as measurements, simulations and programming;
- fault indication.

For simple faults, not all steps are applied. If, during the initial data analysis, the fault is immediately apparent, no further steps are carried out. At this stage, the fault is indicated and the diagnosis completed.

The steps in the diagnostic procedure form the diagnostic routes. They should be as short as possible and lead to the goal, i.e. the detection of a fault. Figure 1 shows symbolically the steps leading to the detection of a fault, as well as a path where no fault is found despite measuring many technical parameters.

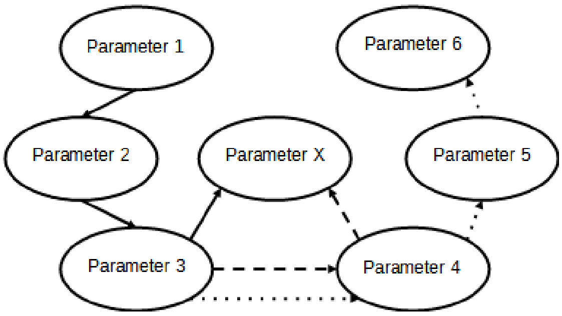

Fig.1. Different diagnostic routes during performance analysis
Designations in the figure: Parameter X is the parameter that indicates a fault. The solid line is the path that is most effective during diagnostics. The dashed line is the path that leads to the detection of a fault, but not the optimal path. The dotted line is an analysis of multiple parameters, not leading to the detection of a fault.

If the fault was not identified during the initial analysis of the reading parameters, the diagnosis process must be continued by analysing the parameters. At this stage, the diagnostician selects representative parameters from the entire set and determines the dependency function of one parameter on another. He or she then analyses the parameter values in the selected diagnostic function. Diagnosticians do not call this activity function selection, but use different terminology. They divide in-service data analysis into analysis during static measurements and dynamic measurements. These are similar terms, but not the same as data analysis and analysis after a fault-specific diagnostic function selection.

During static tests, we read the parameters from the measuring instruments or from the scanner and analyse them for correctness at a given point in time. We do not make any changes to the operating process of the equipment concerned. In dynamic tests, on the other hand, we make changes that alter the parameter values. This creates a function of the dependence of the parameter under investigation on other parameters whose value changes during the measurement.

An example is the battery charging voltage. Although the process of charging the battery is a dynamic process in the physical sense, the voltage value parameter can be called a static parameter if measurements are made only at idle and with a constant engine load. Dynamic tests are when the speed is changed or the engine load changes. If, during static measurements, the parameter values clearly indicate a fault, the diagnosis process is complete. Otherwise, it may be that the voltage is only abnormal during additional load, for example when the air conditioning is switched on. In this case, the diagnostician introduces a function in which the charging voltage parameter is dependent on the load variable.

Fig. 2 presents an example of a study of four parameters concerning the air path of a diesel engine. Positioning the cursor at selected operating points, in the figure this is frame number 118, allows the values of the technical data to be analysed in detail.

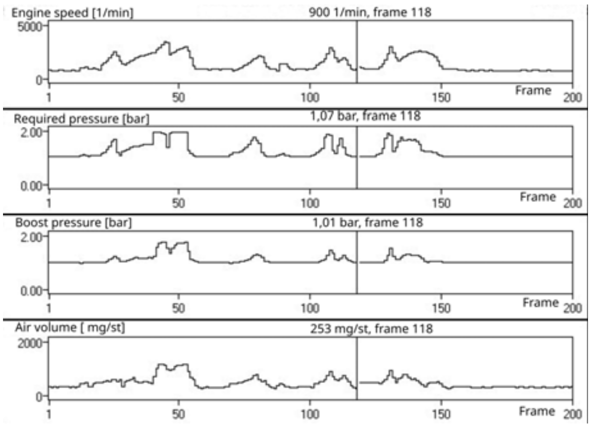

Fig.2. Speed dependence function of air intake and turbocharger pressure

In most diagnostic measurements, parameters are analysed as functions of multiple variable parameters. Depending on the damage case under investigation, the diagnostician introduces a function into the diagnostic process to assign the dependence of the Y parameters on the X parameters. The sets X and Y are selected by the diagnostician based on his theoretical knowledge and experience. The study analysed 96 cases of carrying out diagnostics on various functional systems in which no damage was detected during the first diagnostic stage. The number of parameters entered for analysis by the diagnostician, the function the diagnostician entered and the time the fault was detected were documented. Once the fault was detected, i.e. the diagnostic was completed, the steps the diagnostician performed were analysed. The analysis consisted of a discussion of the choice of parameters and functions, with a view to optimising the diagnostics. The diagnosticians evaluated their work and critically stated how many and what most representative parameters they would select next time, as well as which diagnostic functions they would introduce. This set was referred to as set O. Statistical testing showed that out of the 96 cases studied, in 34 cases the diagnostician would choose a smaller or different set of parameters to analyse. In 2 cases, despite working for eight hours, no fault was detected [7, 8].

Summary

The consequences of a poor choice of parameters.

The choice of operating parameters when searching for a fault is a decisive step that can result in moving closer to the detection of the fault, but also moving away from finding the fault. The effect of moving away from the fault is to make the wrong repair decision, for example, replacing components unnecessarily. This leads to higher costs and longer diagnostic times.

Selection of a few or a dozen current parameters, a way of finding the fault in the event of the same error being reproduced by several or more controllers.

Due to the elaborate electronic systems in the car, the symptoms of damage are often ambiguous. There are many complex dependencies in the operation of the various functional systems that lead to this ambiguity. In the event of damage, new dependencies arise that were not anticipated and are difficult to investigate. In addition, functional systems connected by communication networks duplicate error codes many times. One diagnostic method in such difficult cases is to select a few or a dozen current parameters that are analysed. Changes in the values of these parameters create dependency functions between them, which makes it possible to detect a fault.

Revision of standard and introduction of new diagnostic methods.

The standard diagnostic methods should be corrected in terms of the selection of performance parameters to be analysed. In new methods, the parameter selection stage should be optimised. The experimental work described in this thesis makes it possible to conclude that the analysis of a maximum of a dozen parameters makes it possible to detect faults even when dozens of controllers are installed in a car. New diagnostic methods should be based on capturing only those parameters that unambiguously show faults in the car [9, 10, 11].

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