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CHANGE IN ENGINE POWER IN THE EVENT OF ELECTRONIC COMPONENTS FAILURES

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Abstract

In a conventional internal combustion engine, only electrical controls are used to prepare the fuel mixture. All parts must operate flawlessly in order for the vehicle and its components to operate correctly. Road safety may be negatively impacted by the failure of specific components. The purpose of the study was to ascertain how much the malfunction of particular electrical components affects how the vehicle operates. The vehicle's individual electronic parts were removed, and the engine power was then assessed. The primary determinant of a vehicle's technical condition is thought to be its engine power. The preparation of the combustion mixture was affected by the individual component disconnections, which reduced the vehicle's performance. A vehicle with an in-line four-cylinder engine was used for the experiment, which was conducted in a lab setting. This vehicle's eight components were gradually disengaged. The change in engine power was observed while they were disconnected. The measured values were always evaluated in terms of an automobile that had no defects and was in excellent condition. The study's findings demonstrate that there are circumstances in which a vehicle's usual operation is adversely affected when one or more of its electrical components malfunctions.

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1. Introduction

A significant problem the world is currently confronting is climate change [12]. Its pollution is one among the primary causes of climate change. Serious issues with public health are also brought on by this pollution [5]. Air pollution may be caused by a variety of things, including garbage incineration, industrial exhaust emissions, and vehicle and truck exhaust pollutants. The population's health is extremely perilous in areas where automobile exhaust gases are the primary source of air pollution. Numerous studies [3, 13] have demonstrated how crowded certain locations, particularly junctions, are. Numerous ailments are linked to air pollution, according to studies, which raises healthcare expenditures. These include the price of medical treatment and the loss of production [16, 20, 30].

Currently, one of the industries with the highest CO2 emissions is transportation. Among all means of transportation, the road transport sector ranks as one of the biggest emitters with a proportion of emissions of 72%, followed by air 13.4%, rail 0.5%, water 13.6%, and others 0.5%. It has been shown that passenger cars account for 60.7% of all emissions, out of a total contribution of 72%. This represents one of the primary contributors of the issue's currentness. There is currently a lot of pressure, particularly on automotive industry, to permanently reduce these emissions. The European Union is attempting to compel manufacturers to create greener automobiles [4].

Both a procedure for the integration of public passenger transportation within metropolitan areas and a suggestion for crucial components to enhance road safety are discussed [29]. Vehicles that use alternate forms of propulsion, such as CNG, LNG, or electricity, are becoming more popular right now [10, 11]. Even if the number of newly registered automobiles is rising, it still represents a small portion of all vehicles registered. However, as a result of upcoming laws controlling CO2 emission, these figures need to continue rising. Many businesses believe that alternative propulsion vehicle operating is more important than advertising [18]. In today's automobiles, emission reduction has also taken on significant importance [14, 31]. Vehicle manufacturers work hard to create models that emit the fewest pollutants feasible when driving [15, 17, 24].

The usage of electronics in automobiles has substantially increased due to the implementation of more strict emission requirements. A clear correlation exists between an internal combustion engine's technical complexity and the vehicle's active safety. The parts involved in fuel mixture preparation have the responsibility of optimising the engine's combustion so that it emits the fewest emissions feasible [2]. Mahdina et al. provide evidence for it in their study. Their research established that a vehicle that operates with electronic components produces fewer emissions than one that does not. They looked at fuel usage as well, which was less than for manually propelled cars. [21].

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OBD (On-Board Diagnostics) technology is one of the major technologies used to regulate emissions and diagnose defects in today's automobiles [19, 23]. Data problem codes are generated if the system does not correspond to the chosen OBD component (DTCs). Devices that can read trouble codes from the car fault memory are easily accessible on the market. They give technicians details on the damaged component in their output [25, 26]. A diagnostic tool that could recognise error messages stored in the fault memory was employed in the research as well.

The MIL warning light, which illuminates on the vehicle's instrument panel, might alert the driver of a problem with one of the electronic engine management components. OBD threshold restrictions. There are instances where a defect that is recorded in the ECU memory does not result in the MIL lighting up when the vehicle is in operation [7, 8]. In this instance, the vehicle's driver is not alerted of the component failure. Such a vehicle may produce excessive exhaust emissions, damage to engine components, and last but not least, excessive exhaust emissions, all of which have an adverse effect on road safety.

The power of the engine was tested as part of the study. Vehicle manufacturers frequently offer information on engine power [6, 32]. There are many forms of power that may be identified when measuring it on a roller dynamometer:

- engine power is assessed using the power cylinder brake without taking into account the relevant international regulations (ISO, DIN, EWG),
- corrected power: computed using calculations based on the relevant international standards when measuring the power cylinder brake (ISO, DIN, EWG). The engine listed per the manufacturer's specifications has the corrected power. It is a power that is influenced by environmental factors including air pressure, humidity, and temperature.
- power on wheels: This is the amount of power the vehicle can generate when rolling.
- power dissipation: This figure represents the total amount of power lost across all passive and rotating resistors. These include losses on the wheels, losses due to gear, differential, and bearing engagement, among others [22, 34].

The study looked at how much engine performance is reduced when a certain component malfunctions. At each electronic component failure simulation, engine power is monitored. The investigation shows how functional a car with particular electrical fuel preparation faults is. The driver's knowledge of the failure of the chosen electronic component will be tracked throughout the research to determine whether the driver is also aware of the failure of his vehicle. In subsequent study, it may be feasible to concentrate on modifying the generation of emissions related to the disconnection of the electronic component, as vehicle emissions have a detrimental effect on the environment.

2. Methodology

The goal of the research is to determine changes in the performance of the tested vehicle after disconnecting the electronic components that are directly involved in the preparation of the combustion mixture. Measurements were performed in laboratory conditions and

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driving tests were carried out on the MAHA MSR 1050 roller dynamometer. During individual measurements, selected electronic components were disconnected.

The data collection process can be seen in Figure 1. The measured vehicle is placed on the MAHA MSR 1050 cylinder dynamometer. Before the research, the vehicle was checked for hidden faults so that the results of the research were not affected. The BOSCH KTS 540 diagnostic device was used to check the electronic components. A special program from the BOSCH company was used when working with this device. As part of checking the vehicle's technical condition, the fault memory of the engine control unit was read. No malfunctions were noted in the ECU. An emissions inspection was also carried out within the scope of the emissions inspection. The results of emission tests met the values prescribed by the manufacturer.

After performing the tasks, the vehicle was ready for measurement. In the MSR computer program, we called up the test under the name "continuous performance measurement". In the first step, the performance was measured in a fault-free state. Subsequent disconnection of selected components was followed by cycles of engine performance measurements. The main goal was to monitor the drop in performance due to the disconnection of the selected component.

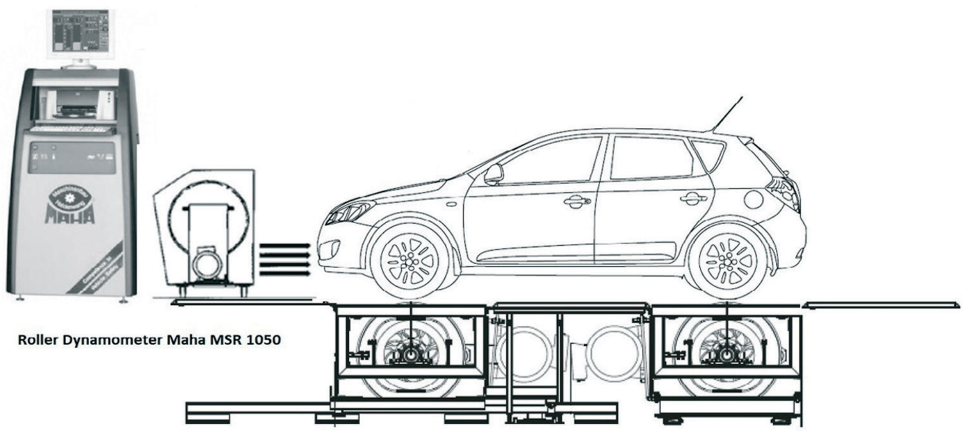

Fig. 1. Test stand scheme [author]

2.1. Measured vehicle

The research was carried out on a Kia Ceed vehicle (Figure 2) with technical parameters that are in Table 1. All engine performance measurements were repeated 10 times in order to increase accuracy. The results, which in their course represented non-standard values, were removed from the statistical file. It is possible to claim that these are measurements that showed extreme values.

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Fig. 2. Measured vehicle KIA Ceed [author]

Tab. 1. Technical parameters of the vehicle Kia Ceed [author]

Technical parameters of the measured vehicle	
Brand	KIA
Trade name	Cee´d
Engine code	G4FC
Number of cylinders	4
Cylinder displacement	1,591 cm^3
Highest engine power	90.00 kW
RPM at max. moment	6,200 RPM
Highest design speed	192 km/h
Fuel type	Petrol
Length	4,265 mm
Width	1,790 mm
Height	1,480 mm
Operating weight	1,163 kg
Maximum permissible total weight	1,710 kg

2.2. Data collection process

The subject of the research is the monitoring of changes after disconnection of the selected electronic component. Above all, it concerns the monitoring of selected operating characteristics of the vehicle, especially engine performance. The simulation of failure of selected electronic components within the engine control was caused by a signal interruption between the component and the engine control unit. For research purposes, failures of electronic components in the form of sensors, which are an essential part of the vehicle, were simulated. Only one sensor at the time was disconnected. Namely:

- Throttle position sensor,
- Crankshaft position sensor,

- Oxygen sensor,
- Manifold air pressure sensor (MAP sensor – manifold absolute pressure sensor),
- Coolant temperature sensor,
- Camshaft position sensor,
- Injector,
- Ignition coil.

When simulating a failure of the mentioned electronic components, the operation of the control unit as well as the engine itself can be negatively affected. The measurements were compiled in sequence. In no case was the failure of two components simulated simultaneously. The procedure that guided the research can be seen in Figure 3.

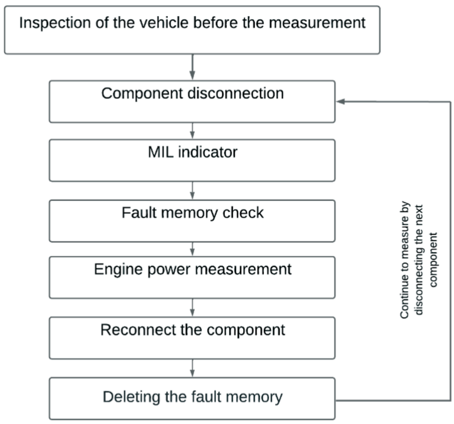

Fig. 3. Methodical research procedure [author]

In the next part (Figure 3), it is possible to follow the procedure that guided the research. It is a process by which data was obtained during individual measurements. Before starting the measurement, an inspection of the measured vehicle was carried out. In particular, components were monitored, the failure of which could invalidate the measurement and the conclusions drawn. Vehicle diagnostics and fault memory data confirmed that the vehicle is in fault-free condition. As a reference, comparative measurements of engine performance were made. With the results of this measurement, we further compared the results of measurements during simulations of failures of individual electronic components.

2.3. Roller dynamometer

Engine power is one of the basic operational characteristics of the engine, but also of the entire vehicle. On the MAHA MSR 1050 roller dynamometer with inter-axle regulation, changes in engine performance were monitored during simulations of individual failures of electronic components. The rollers on which the wheels of the test vehicle roll are raised

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above floor level, which improves the flow of cooling air. This ensures that we can perform long-term testing without the risk of heat build-up. According to the study [33], it is possible to simulate driving on a cylinder dynamometer as real road traffic conditions.

It is also possible to carry out the following measurements on the roller dynamometer: engine power measurement (continuous or discrete), load simulation (constant tractive force, constant speed, driving simulation, constant engine speed), engine flexibility measurement, tachometer control [22].

3. Research results

The output of the individual measurements is the quantification of the impact of disconnecting the electronic component on the operation of the vehicle. The measured results are compared with the condition when no faults were detected on the vehicle. This condition is called "NOT FALUT". Measurements are repeated 10 times. After removing extreme values (where unsuccessful measurements were made), the output of 8 measurements was taken and processed. For research purposes, average data values of individual measurements were processed. Failures of the electronic components were simulated until all measurement cycles had taken place. The detailed process is described in Figure 3.

Tab. 2. Average values recorded during performance measurement [author]

Monitored Values	P_{ENGINE}	P_{WHEELS}		P_{DRAG}
	[kW]	[kW]	[%]	[kW]
NOT FALUT	**90.4**	**68.60**	**75.88**	**21.80**
Throttle position sensor	88.51	66.93	75.61	21.59
Crankshaft position sensor	39.83	29.33	73.65	10.38
Oxygen sensor	89.14	67.38	75.59	22.46
Manifold air pressure sensor	62.23	48.05	77.22	13.57
Coolant temperature sensor	89.08	67.73	76.02	21.25
Camshaft position sensor	88.78	66.44	74.84	22.26
Injector	55.61	36.26	65.21	19.34
Ignition coil	59.63	39.72	66.62	18.94

Table 2 shows the measured averages. According to the obtained data, the observed decrease in engine performance was caused by the simulation of malfunctions of selected electronic components. Measurements performed on a fault-free vehicle are used as reference measurements. This measurement is marked "NOT FALUT". Based on this, initial changes in engine performance can be monitored after individual measurements have been taken. With wheel power, it is possible to track the percentage change in power depending on the change in engine power. For simplicity, only the amount of engine power loss can be compared, as the following relationship applies:

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$$P_{engine} = P_{wheels} + P_{drag} \tag{1}$$

were: P_{engine} – total engine power
P_{wheels} – power on wheels
P_{drag} – power drag

In the following measurements (Figure 4), specific values of vehicle performance changes during the simulation of malfunctions of selected electronic components were addressed. The most significant decrease in engine performance was recorded by the disconnection of the crankshaft speed sensor and injection valves. When the crankshaft sensor is disconnected, the engine control unit does not have information about the revolutions of the crankshaft, nor about the detailed position of the individual pistons in the engine cylinders. In the second case, the control unit does not receive the information that it should inject fuel into the combustion chamber in the disconnected cylinder. A significant deterioration in performance is also observed when the pressure sensor in the intake manifold and the ignition coil in one of the engine cylinders fail. However, these components are the actuators of the engine control unit. Logically, their failure can significantly affect the process of preparing the fuel mixture. These factors also have a negative impact on the safety of vehicle operation.

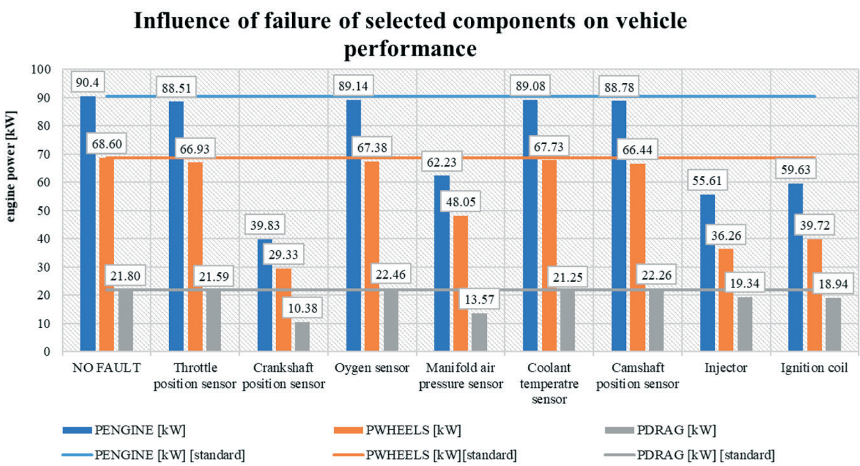

Fig. 4. Effect of failure of selected components on performance [author]

Figure 4 shows how disconnecting one electronic component affects engine performance. All measurements are compared to what the vehicle would look like without the fault. When selected components are disconnected, performance drops dramatically compared to when the vehicle is in faultless condition. The observed decrease occurs when various components are disconnected, namely: crankshaft speed sensor, intake manifold pressure sensor, injection valves, ignition coil. The graph below (Figure 5) shows the average drop in engine power after disconnecting selected components.

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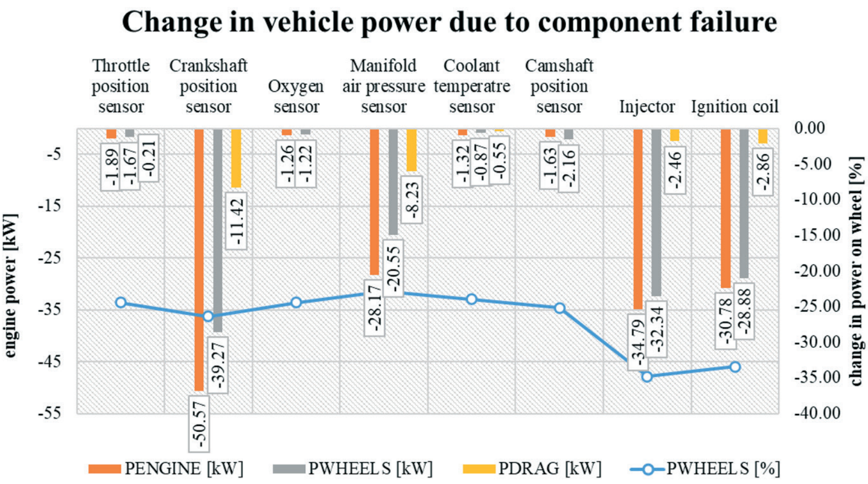

Fig. 5. Change in vehicle power and torque caused by component failure [author]

The graph (Figure 5) shows the reduction in performance due to disconnection of a given component. Power loss is given in kW. The power loss to the wheels, the engine power loss and the magnitude of the power loss are determined.

It can be seen from the figure that the biggest loss of power can be recorded by disconnecting the crankshaft position sensor, that is 50.57 kW, this means that the engine power has decreased by almost 50% compared to the fault-free condition of the vehicle. Another significant loss of power was recorded when the pressure sensor in the intake manifold was disconnected (28.17 kW), power was also reduced by disconnecting the injector (34.79 kW). By disconnecting the ignition coil, the power was reduced by an average of 30.78 kW. As a result of the disconnection of these components, the vehicle exhibits significantly reduced performance. When disconnecting the other monitored components, the engine did not significantly change its performance. Engine performance with these components disconnected was comparable to the fault-free condition.

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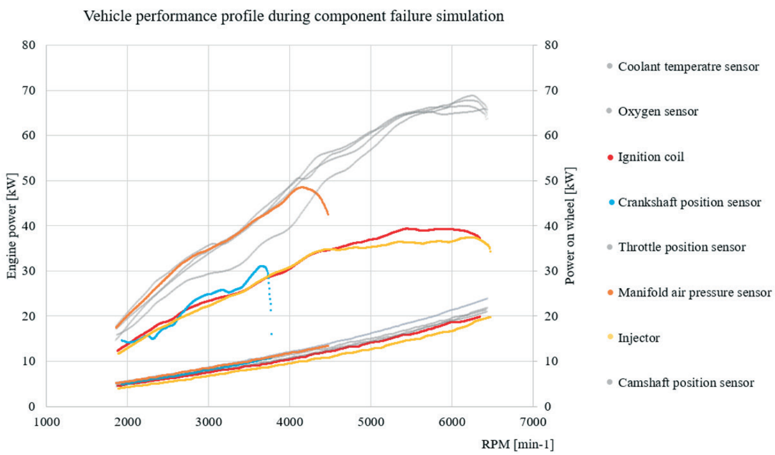

Fig. 6. The course of performance measurement in the event of a failure of selected components [author]

In Figure 6, it is possible to observe the real course of engine performance and wheel performance during the simulation of errors of selected electronic components. Components whose disconnection will not change engine performance are marked in gray in the diagram. Components that significantly degrade engine performance are highlighted in different colors in the diagram. When the internal combustion engine is running, not all the power is transmitted directly to the wheels of the vehicle. Part of the vehicle's power is wasted. These losses are influenced by various factors. The part of the power that is related to the movement of the vehicle is the power at the wheels. Therefore, the power does not reach a value equal to the engine power. During the fault simulation, it is possible to observe how the power on the wheels changes. For components that cause a loss of engine power, some of the power delivered to the vehicle's wheels will also be reduced.

A Table 3 was created for the resulting summary of the research, in which it was possible to monitor the identified indicators. In case of individual malfunctions of electronic components, it is possible to monitor whether the driver is alerted to the malfunction by the MIL light. Another message is the error code displayed after reading the fault memory of the engine control unit. The last column evaluates the engine performance. We receive basic data on whether the vehicle achieves lower performance when selected components fail.

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Tab. 3. The influence of component disconnection on the evaluated parameters [author]

Monitored values	MIL indicator	Fault memory error	Power measurement result
NO FAULT	off	without record	without loss of power
Throttle position sensor	off	P0123	without loss of power
Crankshaft position sensor	off	P0339	power loss
Oygen sensor	off	P0030; P0134	without loss of power
Manifold air pressure sensor	off	P0108	power loss
Coolant temperature sensor	off	P0118	without loss of power
Camshaft position sensor	off	P0343	without loss of power
Injector	lights / flashes	P0201	power loss
Ignition coil	lights / flashes	P0300; P0301	power loss

Table 3 shows the extent to which vehicles are affected by electronic component failures. Certain malfunctions of selected components have no or minimal effect on vehicle operation. This means that the performance of the vehicle remains the same and the driver is not informed of the fault (the MIL does not light up). These components are the oxygen sensor and the throttle position sensor. The driver has no information about the fault until the vehicle is connected to the diagnostic system, which displays the error code from the engine control unit.

Another group of components are those whose failure is already detected when they are produced. These are the coolant temperature sensor and the camshaft sensor. In the event of a temperature sensor failure, the radiator fan immediately starts at maximum power. This is due to the fact that the control unit does not receive information about the temperature of the coolant from the sensor and thus prevents damage to the engine by overheating. In the case of the crankshaft speed sensor, the engine speed is temporarily not displayed to the driver. They reappear after a short time, but their value is calculated. The engine control unit calculates them using other sensors. The driver does not receive information about the failure of this group of components in the form of a MIL light on the dashboard.

The last group is the components, the failures of which are recorded by a loss of performance. This significant loss is recognized by the driver during the operation of the vehicle. A significant power loss was found by disconnecting the crankshaft position speed sensor, intake manifold pressure sensor, fuel injectors and ignition coils. When these components fail, vehicle performance can be significantly reduced and exhaust emissions can also increase. The engine power drop is shown in Figure 7.

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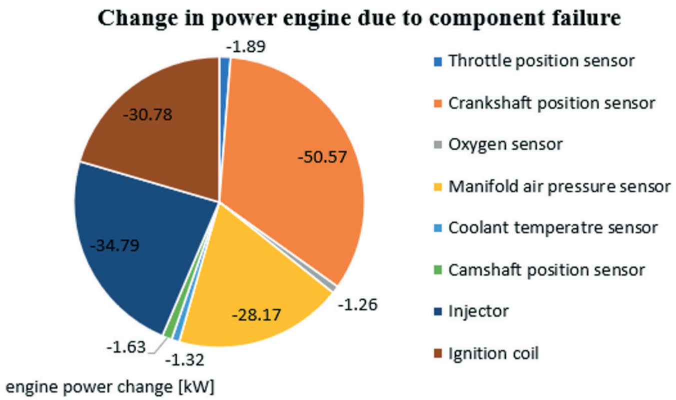

Fig. 7. Change in power engine due to component failure [author]

Figure 7 shows the drop in engine power in kW. When the pressure sensor in the intake manifold fails, the vehicle loses power (by 28.17 kW) and the driver is not informed of the failure. When simulating the failure of the crankshaft speed sensor, the power was reduced by almost 50 kW. The control unit works in emergency mode, which does not allow higher engine speeds to be reached. When it fails, it is difficult for the vehicle to stabilize the engine speed in a specified range in a specified time interval. The driver also did not receive any information about this malfunction (MIL does not light up). The only situation when the driver is informed via the MIL light is when the ignition coil is disconnected and the injector is disconnected. Due to these malfunctions, the MIL on the dashboard came on and started flashing. These are faults indicated according to approval regulations. Also for this reason, it can be stated that the vehicle operator should ensure that during each vehicle maintenance, the fault memory is checked and no faults are recorded in it.

4. Discussion and conclusion

The research focuses on the quantification of engine performance data under conditions of simulated electronic engine control failure on a vehicle. It describes how the simulation of failures of selected components affects the operation of the vehicle. Several studies have dealt with changes in engine performance depending on the fuel used [9, 28, 34].

The main part of the study is the analysis of engine performance during a simulated failure of selected components. When the crankshaft speed sensor, MAP sensor, fuel injectors and ignition coils fail, engine power will be reduced. When the crankshaft position sensor was disconnected, the engine power dropped most significantly, 50.57 kW. Azzoni et al. after conducting a similar study, were able to diagnose engine malfunctions using a crankshaft speed sensor. The study is based on monitoring the fluctuation of crankshaft revolutions [1]. In another study, Seifi et al. described the change in engine performance after adding water to the fuel. After adding water, the power and torque of the engine will increase. In terms

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of performance measurement, these studies are similar in that motor performance is monitored and changed by environmental influences [32]. The results of the failure simulation for the selected components are the operation of the vehicle in limited conditions. In these cases, the characteristics of the vehicle will not be comparable to the characteristics of the vehicle in a fault-free condition. There are different ways to monitor the effects of component failures. This is proven by the study of Organ et al. It addresses the impact of a vehicle breakdown on its operation [27]. In the study, they monitored the impact of the damage on the kilometer driven by the vehicle. The results of the study showed a significant increase in emissions of selected types.

Based on this information, an increase in emissions can be assumed, even if they are not monitored. The above studies clearly point to the importance of the proper functioning of the engine hardware system for optimal fuel consumption and proper vehicle operation. When analyzing the data obtained by measurement, it was proven that the damage or incorrect function of selected electronic components of the engine management has a significant impact on the operation of the vehicle. Any damage to an electronic component manifests itself in a specific way. The impact of damage to selected components on engine performance was monitored in the research.

The conclusions of the study contain important knowledge in the field of fuel mixture preparation for engine management. The obtained results point to the impact of damage to individual electronic components in internal combustion engines. Correct functioning of components and vehicles as a whole contributes to overall road safety. Research proves that every fault simulated on a representative vehicle has an impact on the vehicle's operation and also affects the safety of the operation. At least because the fault is manifested as a code written in the fault memory of the engine control unit. In addition, it is possible to declare and recommend a diagnostic check of the vehicle at each maintenance, as studies have confirmed that the driver does not need to know anything about the damage caused. Damage caused by malfunctioning electronic components can cause the vehicle to produce more emissions. In further research, these data can also be tracked.

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6. Nomenclature

CO carbon monoxide
CO_2 carbon dioxide
OBD on-board diagnostics
RPM revolutions per minute
MAP manifold absolute pressure sensor
kW kilowatts
P power
CNG Compressed Natural Gas
LNG Liquefied Natural Gas
ECU engine control unite
DIN Deutsche Industrienorm
EWG Europäische Wirtschaftsgemeinschaft
MIL Malfunction Indicator Light
DTC data trouble code
ISO International Organization for Standardization

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