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# A FUNCTIONAL AND TASK FAULT-ORIENTED DIAGNOSTIC SYSTEM FOR WHEELED TRACTORS

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ABSTRACT

The wheeled tractors that are widely used in various branches of the national economy have a superior design. Various types of faults affect the efficiency of work, increase emissions of hazardous substances and fuel consumption, and affect the safety level and the dynamics of the vehicle. To ensure the appropriate and timely location and repair of faults it is necessary to employ complex diagnostic systems. The study outlines the design of a device used in the diagnostics of the condition of a wheeled tractor. Also, examples of diagnostic algorithms and procedures are also presented. The diagnostic system for the wheeled tractor presented herein considerably improves the reliability of the vehicle and limits the consequences of potential defects. The operator of the tractor is notified immediately after the occurrence of a fault, which prevents further damage to other components of the vehicle and reduces the operating costs. The study also presents the results of tests of the diagnostic facility for wheeled tractors. The results of the tests of the unit were additionally verified by using other diagnostic methods, e.g. with the use of a thermal imaging camera.

## Introduction

Wheeled tractors are frequently used in various branches of the economy. The vehicle can be used for farming, forestry, construction works, transport and municipal works. The modern wheeled tractors include various structurally advanced systems and components to automate operation, improve efficiency in working conditions and ensure maximum performance, at the same time limiting fuel consumption and emissions of hazardous substances (Fig. 1). Exhaust emissions from the engine are very harmful for the environment and crop production (Dyer and Desjardins, 2006; Lindgreen, 2005). All components of the wheeled tractor, as illustrated in Fig. 1, require diagnostic facilities.

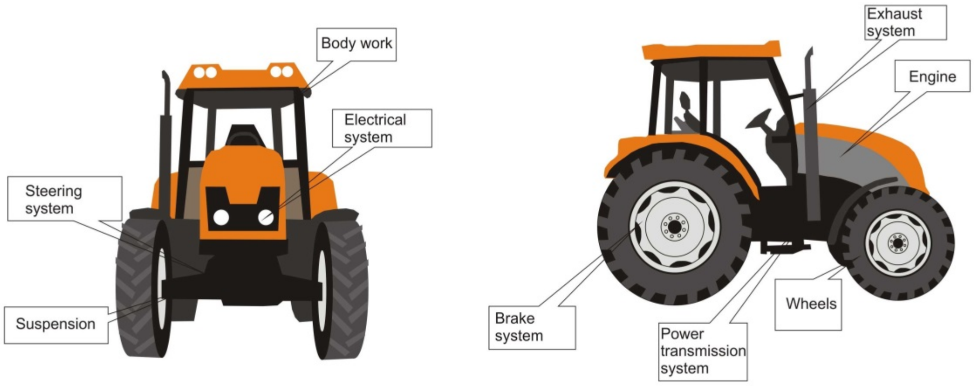


*Figure 1. Basic components of wheeled tractors (Michalski et al., 2014a)*

Modern wheeled tractors utilise advanced mechatronic technologies to manage the operation of various components of the vehicle, including the engine, power transmission system, functional components of the generator, and working elements of machines (Cieślikowski and Pedryc, 2009).

The automatic steering systems implemented in wheeled tractors are able to replace the operator for driving the vehicle, which enables the most efficient mode of operation, with limited fuel consumption and more efficient use of the engine torque and power (Carrera et al., 2010).

The introduction of advanced electronic systems to control and supervise the operation of individual systems and components has facilitated the work and improved the quality thereof, but at the same time resulted in more complicated design of specific components. Wheeled tractors now feature electronic systems to perform vehicle diagnostics with the use of defect code readers (Mamala et al., 2008).

**Diagnostics of wheeled tractors**

The wheeled tractor is able to perform various functions, depending on the demand. Since its work environment heavily depends on weather conditions, the tractor must usually be ready to start work at a moment's notice. Therefore, complex and advanced diagnostic systems are required. The diagnostics of wheeled tractors must ensure the assessment of work efficiency, the status of specific functions in the process of performing operational and transport tasks, exhaust gas emissions during operation, and safety in traffic and in the fields.

In terms of the consequences of damage to wheeled tractors, the damage can be classified as follows (Michalski et al., 2012):

– functional damage ($d_f$), which affects the efficiency of work (power, torque, pull, working speed, fuel consumption);
– emissions damage ($d_e$), which results in the increase of emissions of toxic compounds (and noise), and the increase of fuel consumption caused by the fault of the power

supply system, the combustion system of the diesel engine, and the power transmission systems;
- damage that compromises traffic safety ($d_s$) of the tractor, affecting systems such as: the brake system, suspension, the steering system or the lighting;
- damage that affects the dynamics ($d_d$) of the wheeled tractor, which affects the tractor driving parameters: reduces acceleration, delays the response to change of driving direction, asymmetry or significant drop of power, drive force torque, etc.

In the diagnostic system the user should receive in real time a signal informing them about a fault, and the information that will enable quick and efficient identification of the location of the fault.

The electronic systems installed in wheeled tractors make it possible to identify a fault in the vehicle immediately after the occurrence thereof, thus preventing excessive fuel consumption and further damage (Carrera et al., 2010).

The on-board diagnostics (OBD) installed in wheeled tractors enable the quick identification of damage and prevention of the consequences of potential faults (Krzaczek, 2009).

**The design of the on-board diagnostic system for the wheeled tractor**

The developed diagnostic system for wheeled tractors is based on the vibration- and shock-resistant Fujitsu FUTRO S100 on-board computer. The set also includes an NVOX LCD 10" touchscreen. The computer runs under the Windows XP operating system and has a USB/DeviceNet driver converter. The developed diagnostic system is installed in the computer. The computer is connected via a USB to the I-7565 USB/DeviceNet protocol converter, working as the “master”. The converter is connected Via the CAN (Controller Area Network), to three data acquisition devices ("slave" devices) that capture data from the sensors installed on the wheeled tractor. The "slave" devices have the data concentrator function. They are identified by ID addresses and are fitted with four input (output) data acquisition cards, matched to the ranges and types of the captured signals (Arendt and Michalski, 2013). Fig. 2 illustrates the structure of the diagnostic device for wheeled tractors.

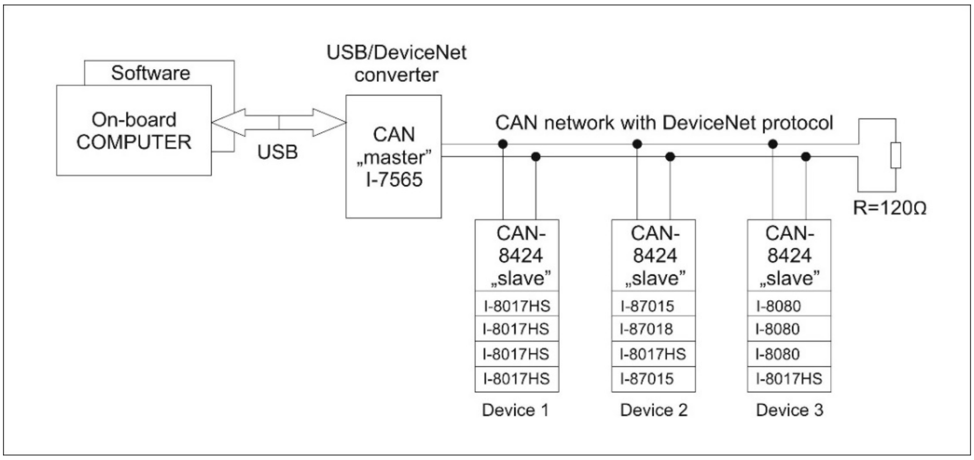


*Figure 2. The structure of the diagnostic device for wheeled tractors (Arendt and Michalski, 2013)*

The diagnostic device is fitted with network devices and data acquisition modules from ICP DAS. The diagnostic device uses four types of data acquisition modules (Arendt and Michalski, 2013):

– I-8017HS - analogue inputs module; acquires the data of 8 analogue signals of the following values: ±10V, ±5V, ±2.5V and ±20mA, or 16 analogue signals, without providing for the negative values;
– I-87015 - analogue inputs module of RTD temperature sensors; acquires data from 7 signals of analogue resistance sensors of various types and temperature ranges; Pt100 sensors were used, with the range of 0ºC ÷ +200ºC;
– I-87018 - analogue inputs module; captures 8 analogue signals of various ranges, included in the range of output voltages of thermocouples; K-type thermocouples were used, with the temperature range of -270ºC ÷ –1,372ºC.
– I-8080 - impulse inputs module; captures 4 binary signals, calculates impulses up- and downwards, and measures frequency; used to measure the rotational speed of shafts by "pick-up" sensors.

The developed diagnostic system enables the connection of up to 144 various sensors.

Three input/output modules handle various sensors. The first module operates at the highest data acquisition speed, and is thus able to handle sensors for dynamic measurements, i.e. the impulse sensors of rotational speed and acceleration sensors used in the vibrational diagnostics. The module is also used to acquire data indicating the current position of the engine crank. The second input/output module acquires data at a lower speed and is used to capture the measurements from the sensors for pressure, fluid levels in tanks, voltage, and current values. The final input module acquires data at the lowest speed and is used to record information from the temperature sensors (Pt-100) installed on specific points of the engine, and the temperature sensors (thermocouple) for exhaust gas from specific cylinders (Michalski and Arendt, 2013).

The Diagnostic System operates under Windows XP with appropriate drivers for handling the USB/DeviceNet converter. Also, special software was developed to handle the DeviceNet, enabling the configuration of inputs and outputs of all expansion modules. The configuration software is used to develop and record the structure of the DeviceNet network, based on SLAVE CAN 8424 devices from ICP DAS and one master device of the DeviceNet network, i.e. I-7565-DNM, also from ICP DAS (Michalski and Arendt, 2013).

In the on-board diagnostic system of the wheeled tractor the data are acquired and processed in real time. At specified time intervals the device acquires and processes data, starts diagnostic procedures, and signals diagnostic status. The software structure consists of the procedures, the objectives, and priorities of execution, which are listed in Table 1. The diagnostic device uses the following diagnostic elements: on-line diagnostics, vibrational tests, engine dynamics tests, steering wheel tests.

A sample set of diagnostic relations of a wheeled tractor, developed on the basis of simulation tests, is provided in Table 2.

Table 1
*Anticipated procedures of the diagnostic device software*

| Item | Procedure name | Priority |
|---|---|---|
| 1. | Procedures of measurement data acquisition and releasing control signals | I |
| 2. | Operating procedure for the touchscreen panel and setting the software to dedicated diagnostic procedures | II |
| 3. | Fast Fourier Transform (FFT) procedure | III |
| 4. | Procedure for determination of the angular accelerations of the crank | IV |
| 5. | Procedures for calculating specific variables of the diagnostic model states | V |
| 6. | Diagnostic procedures | VI |
| 7. | Procedure for signalling the diagnostic states | VII |
| 8. | Other procedures, not listed herein | VIII |

*(Michalski i Arendt, 2013)*

Table 2
*Sample set of diagnostic relations of the wheeled tractor*

| Item | Component | Condition | Name of diagnostic parameter X(t) |
|---|---|---|---|
| 1 | Engine | Faulty cooling system | $T_c$ – coolant temperature - high if $T_{ch} > T_{ch\max}$ |
| | | | $T_{eo}$ – engine oil temperature - high |
| | | Faulty lubrication system | $p_o$ – oil pressure - low |
| | | | $p_{ol} < p_{ol\min}$ |
| | | Incorrect engine combustion process | $T_{f1}$ – exhaust gas temperature on 1st cylinder |
| | | | $T_{f2}$ – exhaust gas temperature on 2nd cylinder |
| | | | $T_{f3}$ – exhaust gas temperature on 3rd cylinder |
| | | | $T_{f4}$ w exhaust gas temperature on 4th cylinder |
| | | | The measurements were taken by the sensors installed in the exhaust manifold at each cylinder. |
| | | | If $T_{kwi} > 1{,}15 \cdot T_{kwśw}$ or $T_{kwi} < 0{,}85 \cdot T_{kwśw}$ , where $T_{kwśw} = \frac{1}{j}\sum_{i=1}^{j} T_{kwi}$ , then the injection system is defective, |
| | | | or the compression pressure on the nth cylinder deviates from normal values. |
| 2 | Gearbox | Gearbox faults | $a_{gbr}$ – level of vibrations of the gearbox and the reduction gear. |
| | | | $T_{gb}$ – gearbox temperature. |
| 3 | Reduction gear | Reduction gear faults | $a_{gbr}$ – level of vibrations of the gearbox and the reduction gear. |
| | | | $T_r$ – reduction valve temperature. |

*(Michalski et al., 2014b)*

On the basis of the recorded data and parameters declared during configuration, the physical values of the variables of the tractor parameters are computed, which cannot be determined in direct measurements. The recorded and computed values are then used in the diagnostic procedure. The cause-and-effect links between the states of fault of specific components of the tractor, and the symptoms, are identified as damage and signalled by appropriate error codes (Arendt and Michalski, 2013).

The developed MSDC-1 diagnostic device (Fig. 3) is composed of: a mobile computer, touchscreen monitor, cabinet with slave devices for data acquisition, USB CAN master converter, and a set of sensors. The MSDC-1 diagnostic device enables the measurement and ongoing analysis of diagnostic signals, and performs the calculations related to the dynamics and kinematics of the tractor's motion.

*Figure 3. MSDC-1 device*

The set of sensors installed on the wheeled tractor includes, *inter alia*, engine crankshaft rotational speed sensors, wheels rotational speed sensors, engine, gearbox and reduction gear vibrations biaxial sensors, vehicle tilt position sensors, pressure sensors at engine inlet system, coolant temperature sensors, engine oil temperature sensors, and sensors for exhaust gas temperature on specific cylinders.

**Tests of the on-board diagnostic facility for the wheeled tractor**

The tests of the on-board diagnostic facility consisted in test drives with different loads and speed, and in different ranges of the engine crankshaft rotational speed as well as tests of a damaged injector cup on the 1$^{st}$ cylinder. The tests allowed us to acquire, *inter alia*, the readouts of the coolant temperature in the cooling system, oil temperature in the lubrication system, and the temperature of exhaust gas from specific cylinders. Sample diagrams of data acquired from the tests of the diagnostic system are provided below.

Fig. 4 illustrates the changes of exhaust gas temperature on specific cylinders during the test. The changes in the temperature of exhaust gas in the exhaust manifold are higher for the first and second cylinder than for the third one.

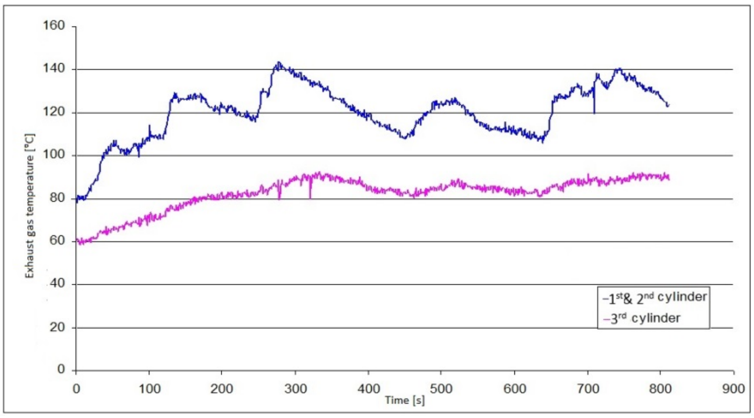


*Figure 4. Changes in the exhaust gas temperature on specific cylinders over time*

Fig. 5 illustrates changes in the temperature of coolant and engine oil over time.

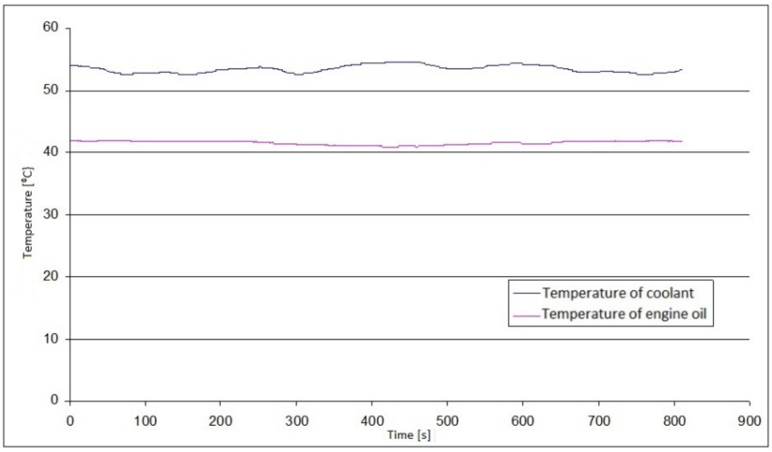


*Figure 5. Changes in the temperature of coolant and engine oil over time*

Fig. 6 illustrates changes in the temperature of the exhaust manifold over time. The blue line indicates the changes in the temperature of the exhaust manifold at the third cylinder; the red line indicates the changes in the temperature of the exhaust manifold at the first and second cylinder. Fig. 7 illustrates the changes in the temperature for the damaged injector cup of the first cylinder.

The operation of the diagnostic system was performed on a functional wheeled tractor. The diagnostic parameters were assessed on the obtained results. Next, the diagnostic parameters were measured for wheeled tractors with a damaged injector cup on the 1st cylinder. In the course of testing the tractor with the faulty injector cup, a drop of exhaust gas temperature on the first cylinder was reported, accompanied by an increase in engine vibration level, and a drop in engine torque, as compared to the diagnostic parameters of a functional wheeled tractor.

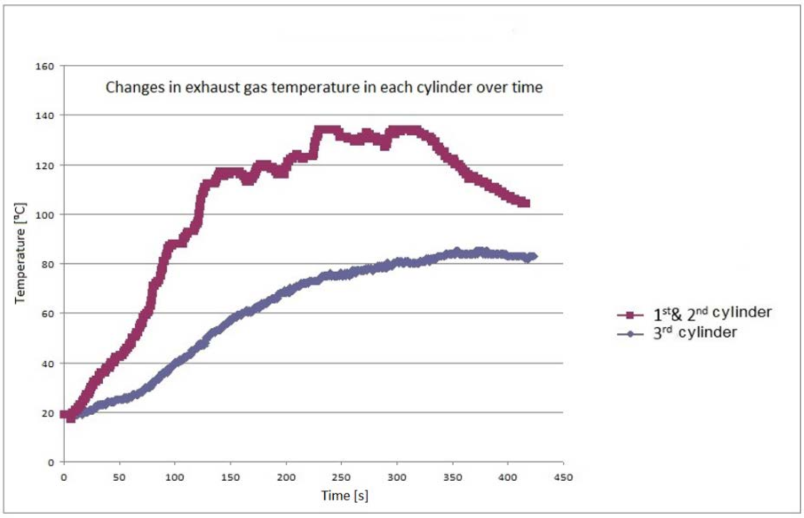


*Figure 6. Changes in the temperature of the exhaust manifold over time*

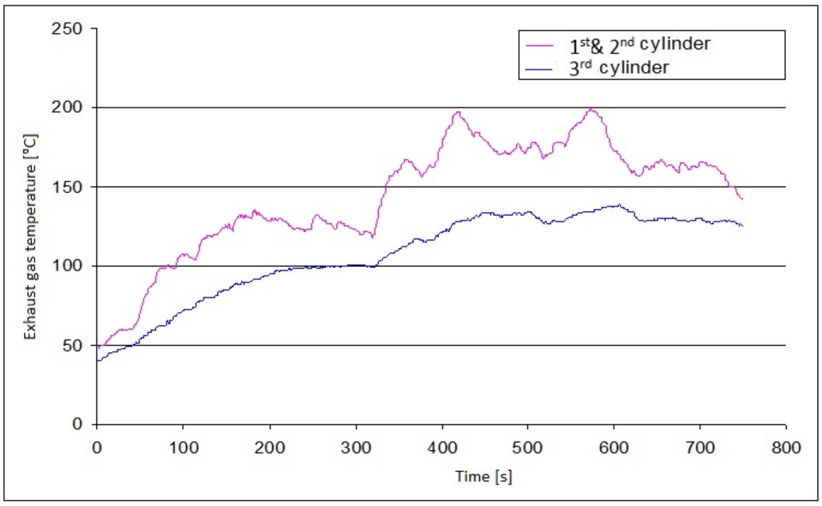


*Figure 7. Changes in the temperature of exhaust manifold with a damaged injector cup on the 1st cylinder*

The temperature values obtained from the diagnostic system were verified with the use of a Flir i60 thermal imaging camera. The obtained measurement values were similar (delta ca. 2.5%). Sample photos of the Ursus MF 255 tractor, taken during the test drives with the use of the thermal imaging camera, are provided in Fig. 8.

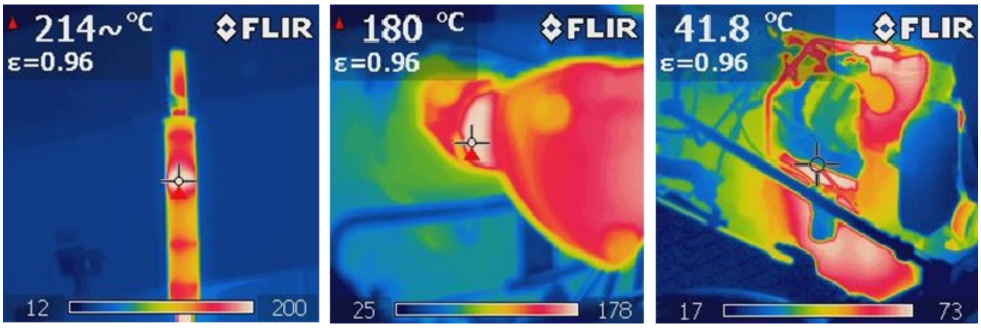


*Figure 8. Images of the exhaust system, exhaust manifold and engine of the tractor, taken by a thermal imaging camera*

Analysing the diagrams of the exhaust gas temperature during subsequent tests, a correlation was observed between the exhaust gas temperature and the engine crankshaft rotational speed, as well as with the engine load. Analysing the diagrams of the coolant temperature and the engine oil temperature, a visible temperature rise was observed during the tests on a warm engine.

## Conclusion

The modern design solutions of wheeled tractors make it increasingly difficult to perform efficient diagnostics with the use of traditional, universal diagnostic methods and devices. The study analysed the conditions that must be met by the diagnostic system for wheeled tractors, and categorised the defects of wheeled tractors into specific classes. The design of the hardware and software of the device developed for the diagnostics of wheeled tractors was presented along with the procedures and algorithms used by the software.

The developed diagnostic systems for wheeled tractors considerably improve the reliability of tractors and reduce the consequences of potential defects, as they allow quick identification of faults, thus preventing more severe damage to the components of the vehicles.

The study also presents the results of the tests of the diagnostic facility for wheeled tractors. The results of the tests of the unit were additionally verified by the use of other diagnostic methods, e.g. with the use of a thermal imaging camera.

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## SYSTEM DIAGNOSTYCZNY CIĄGNIKA KOŁOWEGO ZORIENTOWANY NA NIEZDATNOŚCI FUNKCJONALNE I ZADANIOWE

**Streszczenie.** Ciągniki kołowe, które są wykorzystywane w wielu gałęziach gospodarki krajowej posiadają nowoczesną konstrukcję. Pojawienie się różnego rodzaju niezdatności przyczynia się do ograniczenia efektywności pracy, wzrostu emisji szkodliwych substancji, wzrostu zużycia paliwa, pogorszenia poziomu bezpieczeństwa oraz spadku dynamiki pojazdu. Z uwagi na szybkie przeciwdziałanie pojawiającym się niezdatnościom i właściwą lokalizację uszkodzenia konieczne jest stosowanie rozbudowanych układów diagnostycznych. W pracy przedstawiono budowę urządzenia wykorzystywanego do diagnostyki stanu technicznego ciągnika kołowego. Przedstawiono również przykładowe algorytmy i procedury diagnostyczne. Zaprezentowany system diagnozowania stanu ciągnika kołowego w znacznym stopniu przyczynia się do poprawy jego niezawodności i ograniczenia skutków ewentualnych uszkodzeń, gdyż operator ciągnika po pojawieniu się niezdatności jest zawsze szybko o tym powiadamiany, co zapobiega dalszym uszkodzeniom kolejnych podzespołów pojazdu oraz ogranicza koszty eksploatacji. W pracy przedstawiono także wyniki testów stanowiska diagnostycznego stanu technicznego ciągnika kołowego. Wyniki testów urządzenia zostały ponadto zweryfikowane poprzez wykorzystanie innych metod diagnostycznych, np. pomiarów z użyciem kamery termowizyjnej.

**Słowa kluczowe:** ciągnik kołowy, diagnostyka, uszkodzenie, system diagnostyczny