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ON-BOARD DIAGNOSTIC SYSTEMS IN WHEELED TRACTORS

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Abstract

Periodic inspections in service stations do not always deliver optimal results due to limited service time, restricted scope of the inspection and the absence of working load during the diagnostic process.

Diagnostic systems in modern wheeled tractors do not make full use of the relations between diagnostic symptoms and parameters. Damaged components in a given assembly are not specifically identified.

The diagnostic system for a wheeled tractor determines a tractor's operating parameters based on fuel consumption data, and the identified defects are classified into several groups in view of the consequences they produce: functional defects (u_f), exhaust defects (u_e), defects that jeopardize driving safety (u_s) and defects that affect engine performance (u_d).

A series of diagnostic procedures were developed for the needs of an OBD system in a wheeled tractor. The results of tractor trials indicate that significant mechanical defects lead to changes in various diagnostic parameters. For this reason, a wide range of diagnostic parameters should be analyzed by an OBD system to reliably identify defects and minimize the risk of an incorrect diagnosis. This paper presents an on-board diagnostic system developed at the University of Warmia and Mazury in Olsztyn and the Gdańsk University of Technology. Trial results revealed that the analyzed OBD system is capable of detecting a wide range of tractor defects in real time.

1. Introduction

A wheeled tractor is a motor vehicle that is specifically designed to haul machinery and implements without a self-propelled drive system. Machines and implements are attached to the tractor using a three-point hitch. Wheeled tractors are used in agriculture, forestry, construction, transport and municipal services.

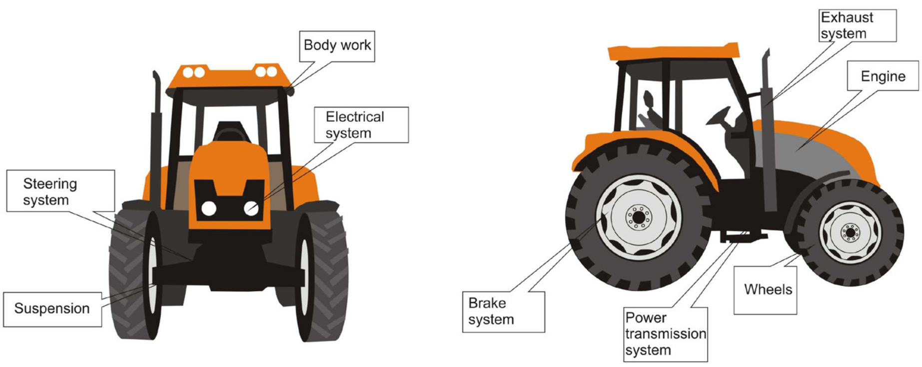

Fig. 1. Diagram of the main components and systems in a wheeled tractor

A wheeled tractor is powered by a combustion engine (Fig. 1) which is largely responsible for a tractor's performance. Modern diesel engines meet stringent emission standards and achieve high performance results.

A tractor's power transmission system comprises the clutch, gearbox, reduction gear, rear axle and portal axles. In all-wheel drive tractors, the power transmission system is additionally equipped with a transfer case, a drive shaft and a front drive axle. The speed range for wheeled tractors is from under 1 km/h to 50 km/h. Torque is an important parameter in tractors. There are two types of power transmission systems in wheeled tractors: rear-wheel drive and all-wheel drive.

Wheeled tractors can be provided with additional subassemblies, including hydraulic lifts for suspended tools and machines, power take-off for powering machines, pneumatic trailer braking systems and external hydraulic systems.

2. Controlling the operation of wheeled tractors

Periodic inspections in service stations do not always deliver optimal results due to limited service time, restricted scope of the inspection and the absence of working load during the diagnostic process.

In the past decade, tractor engines have evolved significantly in terms of the applied functional solutions, structural materials, manufacturing technologies, electronics and IT components for controlling mechatronic systems.

Contemporary tractors and farming machines rely on the latest mechatronic systems for controlling the power transmission unit, functional subassemblies and implements [Cieślikowski 2009].

Diagnostic systems in modern wheeled tractors do not make full use of the relations between diagnostic symptoms and parameters. Damaged components in a given assembly are not specifically identified.

A tractor's parameters should be monitored online to detect possible defects, prevent serious damage to the vehicle and minimize environmental pollution. The first symptoms of technical failure in unmonitored vehicles are often observed too late [Michalski, Gonera 2012].

State-of-the-art tractors are equipped with automatic steering systems that eliminate the need for an operator. This highly advanced solution increases vehicle performance, reduces fuel consumption, optimizes torque and engine output. Defects are immediately detected by an electronic control system, which prevents a long-term increase in fuel consumption and further damage to the tractor [Carrera 2010].

The results of the analysis indicate that diagnostic systems in contemporary wheeled tractors monitor basic operating parameters in the engine and selected assemblies, and they are restricted to parameters that are indispensable for controlling engine operation. In the event of damage to the exhaust system, the diagnostic system will monitor only engine parameters which indicate that safe smoke levels in exhaust gas could have been exceeded, but the composition or smoke levels in exhaust gas are not analyzed [Michalski, Janulin 2012]

A new approach to simulating the operation of wheeled vehicles is needed to ensure compliance with environmental protection regulations and to reduce fuel consumption. Toxic emissions from wheeled tracts significantly affect crop production and pose a serious threat of environmental pollution [Dyer 2006].

Advanced electronic control systems facilitated and improved the quality of control operations in wheeled tractors, but the availability of multiple control options significantly contributed to those systems' complexity. For the sake of simplification, many agricultural tractors are equipped with electronic systems that rely on diagnostic trouble codes [Mamala 2008].

On-board diagnostics (OBD) in an agricultural tractor facilitates the detection and repair of defects and faults in a vehicle [Krzaczek 2009].

To date, tractor defects were analyzed by modeling the operation of diesel engines in computer simulations based on the engine's general characteristics and performance measured at several points. This is a simplified method of determining the most cost-effective areas of engine operation [de Souza 1999].

3. Structure of a diagnostic system in a wheeled tractor

The diagnostic system for a wheeled tractor was designed with special emphasis on:

- streams of diagnostic information addressed to the user,
- model technical solutions for developing a mechatronic damage control system in a tractor,
- generally applicable structural solutions for a given class of tractors,
- standard diagnostic procedures for localizing defects,
- diagnostic knowledge base and inference algorithms.

The diagnostic system determines a tractor's operating parameters based on fuel consumption data, and the identified defects are classified into several groups in view of the consequences they produce: functional defects (u_f), exhaust defects (u_e), defects that jeopardize driving safety (u_s) and defects that affect engine performance (u_d). The adopted model of a wheeled tractor relies on traction values which describe the vehicle's operation and determine its wear in a given load cycle (Fig. 2).

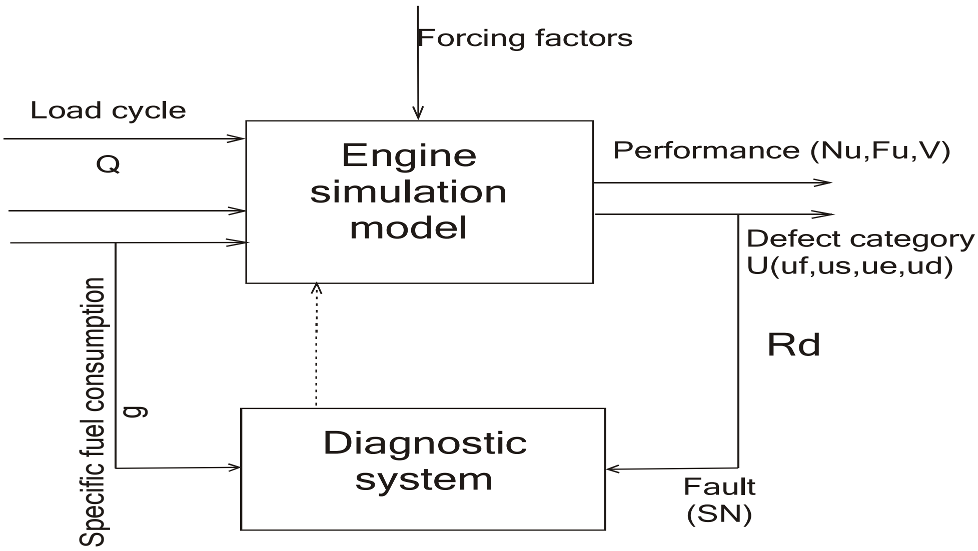

Fig. 2. Diagnostic diagram of a wheeled tractor based on the proposed mechatronic system for monitoring the condition of wheeled tractor (MSMC), where: g – specific fuel consumption, S_N - fault, U - defect category [4]

A tractor's operating status is determined by: driving speed, resistance to motion (of the tractor and implements), mass, gear ratio in the power transmission system, layout of the power transmission system, rolling radius of drive wheels, etc. The severity of damage to tractor components is influenced by the load cycle and material strength. The basic diagnostic symptoms are performance parameters, temperature and mechanical vibrations. Those symptoms are measured with the use of various diagnostic sensors which are presented in Figures 3 and 4.

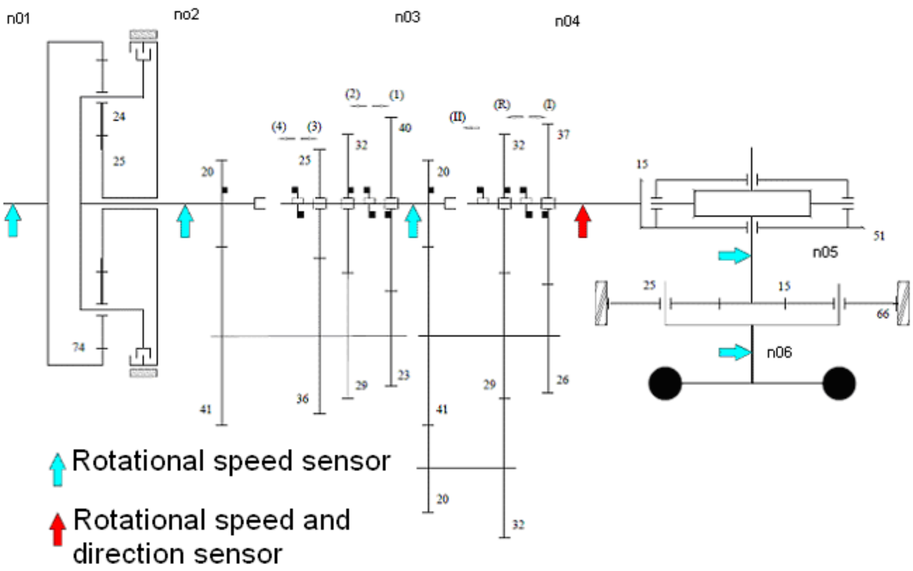

Fig. 3. Distribution of diagnostic sensors in a kinematic diagram of a tractor's power transmission system

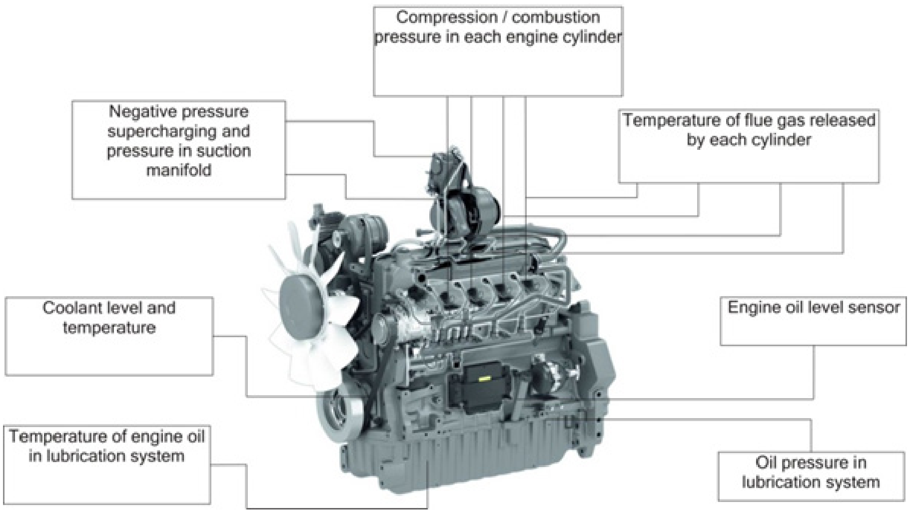

Fig. 4. Distribution of sensors for monitoring engine operation in a wheeled tractor [9]

Operating parameters can also be classified into the following groups subject to the nature of changes in the recorded values:

Constant: coefficient of rolling resistance, weight of performance-ready tractor, trailer weight, operator weight, effectiveness of the power transmission system;

Random: ground inclination, slip ratio of drive wheels;

Declared: engine rotational speed set by the operator, working speed set by the operator, weight of load transported on trailer;

Monitored: engine rotational speed, specific fuel consumption, driving speed, fuel consumption.

A mechatronic diagnostic system of a wheeled tractor (MSDC) can be represented by the following relationship: [Michalski, Arendt, Janulin, Gonera 2014]:

$$MSDC = [\ PI, PS, PZ, PP, PD, CK, R_D\ ], (1)$$

where:

PI – computer subsystem,

PS – control subsystem,

PZ - power supply, data communication and material supply system,

PP – working and auxiliary process subsystem,
PD – diagnostic subsystem,
CK – wheeled tractor,
R_D – diagnostic and control relations.

The main functions of MSDC are:

- monitoring components which affect the operation, safety, performance and toxic gas emissions of a wheeled tractor,
- recording information about component failures,
- recording information about tractor parameters at the moment of damage,
- communicating defects to the operator.

A tractor's diagnostic subsystem has the following elements [Michalski, Arendt, Janulin, Gonera 2014]:

$$PD = [\, E_d\,,\, C_d,\, S,\, M_d\,,\, I\dot{z},\, Op,\, A_d,\, R_d], \quad (2)$$

where:
E_d – set of elements which are diagnosed in a selected monitoring function,
C_d – sensor set,
S – electronic control system (controller),
M_d – data bus,
$I\dot{z}$ – system for the visualization of diagnostic data,
Op – software,
Ad – diagnostic algorithms,
R_d – diagnostic relations.

A diagnostic subsystem in a wheeled tractor:

- monitors a tractor's operating state,
- monitors performance parameters,
- generates error (fault) codes,
- monitors instantaneous fuel consumption,
- registers operating time,
- registers GPS data (map, trace, speed, altitude).

A model diagnostic device, MSDC-2 (Fig. 5), was developed for on-board diagnostics in a wheeled tractor. The device can monitor and analyze up to 20 diagnostic parameters based on the adopted diagnostic procedures in a dedicated application.

Fig. 5. Diagnostic device - MSDC-2 [Photograph by Jarosław Gonera]

4. Diagnostic procedures in a tractor's OBD system

A series of diagnostic procedures were developed for the needs of an OBD system in a wheeled tractor. Selected diagnostic procedures are presented below. In the process of identifying defects, symptoms characteristic of various defects were associated with specific operating parameters.

Evaluation of the technical condition of a wheeled tractor's engine:

T_{ch} – coolant temperature.

Coolant temperature is measured by a cooling system sensor installed in the area of the coolant pump. $T_c > T_{c\max}$, indicates: engine overheating due to overload, coolant pump failure, low coolant level, thermostat failure, radiator failure, cooling system airlock.

T_{ols} – engine oil temperature.

Engine oil temperature is measured directly by a sensor installed in the lubrication system. $T_{ols} > T_{ols\max}$, indicates: engine overheating due to overload, excessive engine speed under given operating conditions /inadequate setting of the power transmission system, low engine oil level, engine seizure.

T_{kw1} – exhaust gas temperature in cylinder 1,
T_{kw2} – exhaust gas temperature in cylinder 2,
T_{kw3} – exhaust gas temperature in cylinder 3,
T_{kw4} – exhaust gas temperature in cylinder 4.

Exhaust gas temperature is measured by sensors installed in the exhaust manifold by every cylinder.

$T_{kwi} > 1{,}15 \cdot T_{kwśw}$ or $T_{kwi} < 0{,}85 \cdot T_{kwśw}$, where $T_{kwśw} = \frac{1}{j}\sum_{i=1}^{j} T_{kwi}$, indicates injector system failure or abnormal pressure in the ith cylinder.

p_{ks} – suction manifold pressure.

Pressure is measured directly by a sensor in the engine's suction manifold. $p_{ks} < p_{ks\min}$, indicates: air filter blockage, blockage of the air supply conduit.

a_s – engine vibration level.

Engine vibration levels are measured directly by a biaxial vibration sensor. $a_s > a_{s\max}$, is indicative of engine failure.

Evaluation of the technical condition of the gearbox (reduction gear and final drive):

a_{spr} – vibration levels in gearbox and reduction gear.

Vibration levels are measured directly by a biaxial vibration sensor installed on gearbox housing. $a_{spr} > a_{spr\max}$ is indicative of gearbox or reduction gear failure.

T_{sp} – gearbox temperature.

Gearbox temperature is measured directly by a sensor installed on gearbox housing. $T_{sp} > T_{sp\max}$, indicates gearbox failure or low gearbox oil level.

Evaluation of the technical condition of the left portal axle (right portal axle):

n_{zl} – left wheel speed, n_s – engine speed, i – overall gear ratio.

Wheel speed is measured directly by a speed sensor. When the differential is locked and the clutch is disengaged, $n_{zl} < \frac{n_s}{i}$ is indicative of power transmission failure.

5. OBD tests

A wheeled tractor was equipped with sensors measuring: engine rotational speed, wheel rotational speed (Fig. 6), engine vibration levels, vibration levels in the gearbox and reduction gear, vehicle position – displacement, pressure in the induction system, coolant temperature, engine oil temperature, exhaust gas temperature in each cylinder (Fig. 6).

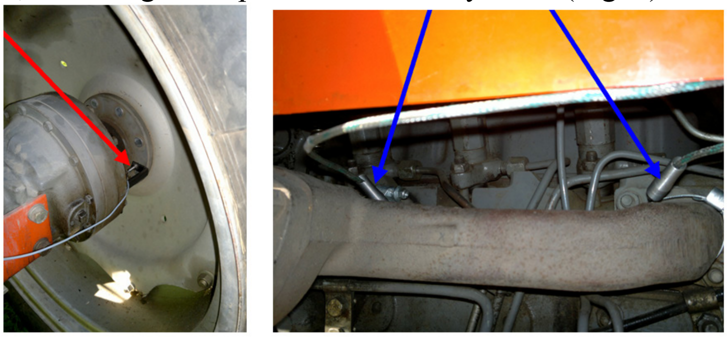

Fig. 6. Rear wheel rotational speed sensor (left) and exhaust gas temperature sensor (right) [Photograph by Jarosław Gonera]

Changes in engine rotational speed during the test are presented in Figure 7. Significant fluctuations in engine rotational speed were noted during alternating motion (700-2500 rpm).

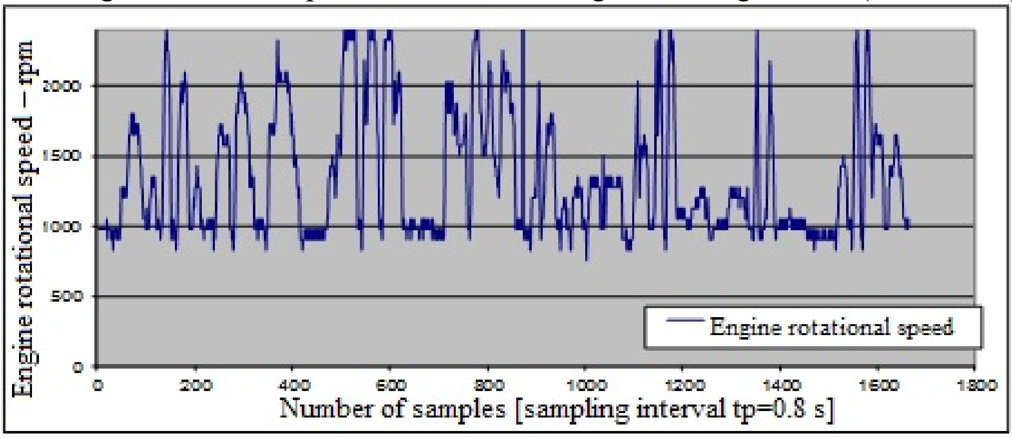

Fig. 7. Changes in engine rotational speed over time

Changes in exhaust gas temperature in each cylinder during load transport are presented in Figure 8.

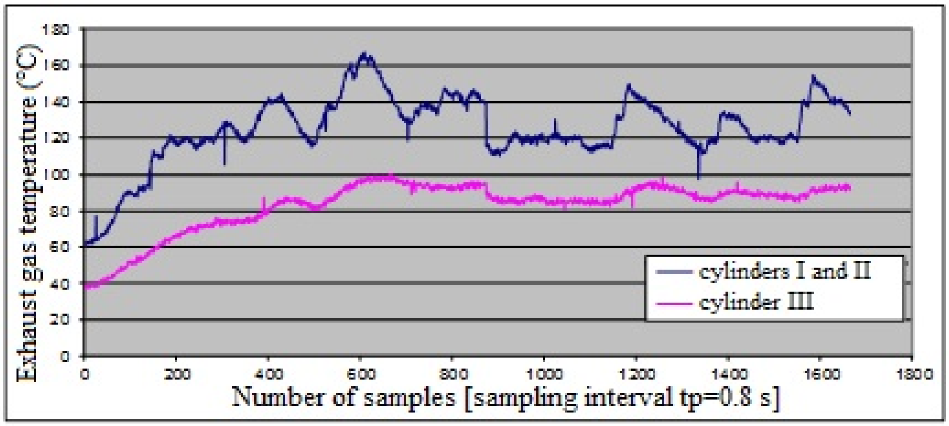

Fig. 8. Changes in exhaust gas temperature in each cylinder over time

Changes in the temperature of the coolant and engine oil over time are presented in Figure 9. Oil and coolant temperature increased with time.

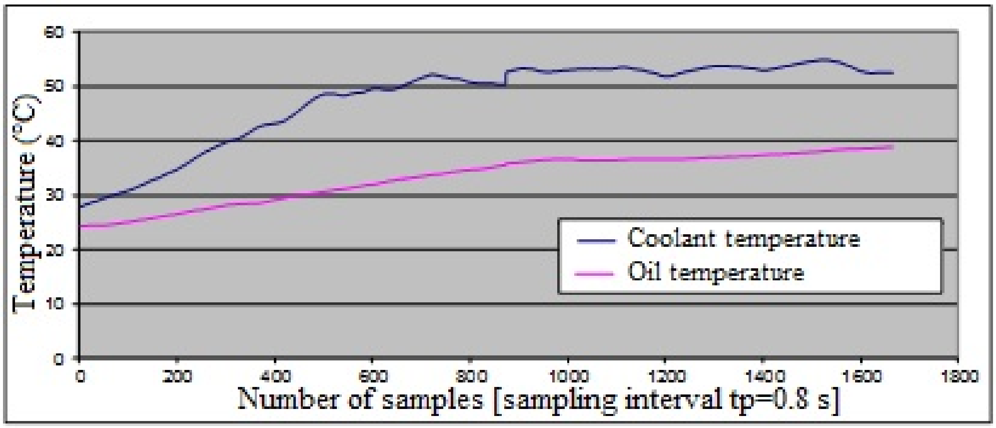

Fig. 9. Changes in the temperature of the coolant and engine oil over time

Engine vibration levels were measured in a parked and operating tractor as engine rotational speed was increased. Changes in engine vibration levels are presented in Figure 10.

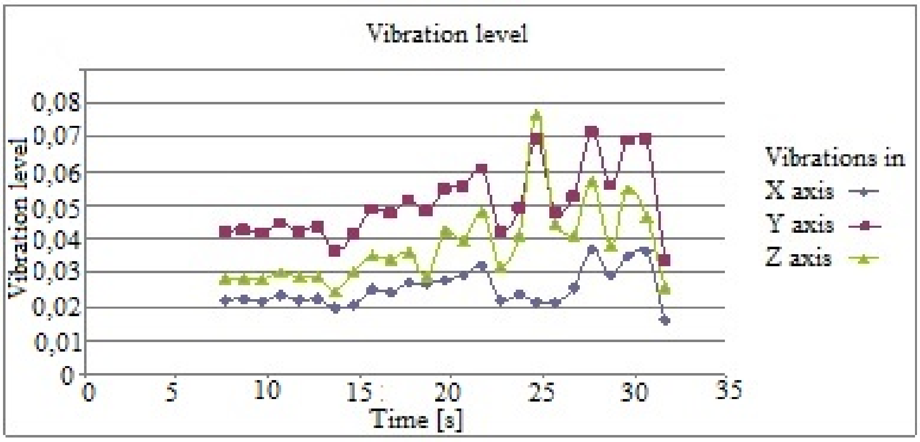

Fig. 10. Changes in engine vibration levels over time

The results of tractor trials indicate that significant mechanical defects lead to changes in various diagnostic parameters. For this reason, a wide range of diagnostic parameters should be analyzed by an OBD system to reliably identify defects and minimize the risk of an incorrect diagnosis.

6. Conclusions

On-board diagnostic systems installed in contemporary wheeled tractors were analyzed in the study. The results of the analysis indicate that most OBD systems monitor the tractor's current operating parameters and control selected subassemblies, but they completely lack dedicated procedures for diagnosing the vehicle's technical condition based on the monitored parameters.

Different categories of defects in a wheeled tractor should be monitored online to identify potentially serious failures and to prevent further damage.

This paper presents an on-board diagnostic system developed at the University of Warmia and Mazury in Olsztyn and the Gdańsk University of Technology [Michalski, Arendt, Janulin, Gonera 2014]. Trial results revealed that the analyzed OBD system is capable of detecting a wide range of tractor defects in real time.

REFERENCES

1. Dyer J., Desjardins R., *Carbon Dioxide Emissions Associated with the Manufacturing of Tractors and Farm Machinery in Canada*, Biosystems Eng. 93 2006.
2. Cieślikowski B., Pedryc N., *Koncepcja nadzoru nad maszynami przez komputer pokładowy ciągnika w czasie rzeczywistym z wykorzystaniem magistrali informatycznej LIN,* Inżynieria Rolnicza 9(118)/2009.
3. Carrera González A, Alonso García S, Gómez Gil J., *Design, Development and Implemementation of a Steering Controller Box for an Automatic Agricultural Tractor Guidance System, Using Fuzzy Logic,* Technological Developments in Education and Automation 2010.
4. Michalski R., Janulin M., *Analiza diagnostyki użytkowej ciągników kołowych*, Monografie, studia, rozprawy nr M29, Wydawnictwo Politechniki Świętokrzyskiej, Kielce 2012r.; ISSN 1897-2691.
5. Krzaczek P., *Ocena parametrów energetycznych ciągnika rolniczego JOHN DEERE 6820 z wykorzystaniem diagnostyki pokładowej*, Inżynieria Rolnicza 8(117)/2009.
6. Mamala J., Jantos J., Augustynowicz A., *Diagnostyka predykcyjna ciągników rolniczych*, Inżynieria Rolnicza 5(103)/2008.
7. De Souza E.G., Santa Catarina A., *Optimum Warking Curve for Diesel Engines, Transactions of the ASAE,* 1999 nr 42.
8. Michalski R., Gonera J., *Monitoring the operation of a wheeled tractor*; Zeszyty naukowe Nauki Techniczne – Budowa i eksploatacja maszyn nr 17, Wydawnictwo Politechniki Świętokrzyskiej, Kielce 2012r., ISSN 1897-2683.
9. Michalski R., Gonera J., Janulin M., Arendt R., *Structural analysis of a wheeled tractor oriented towards damage diagnostics,* Monografie, studia, rozprawy nr M29, Wydawnictwo Politechniki Świętokrzyskiej, Kielce 2012r., ISSN 1897-2691.
10. Michalski R., Arendt R., Janulin M., Gonera J., *Diagnostyka uszkodzeń ciągników kołowych. Identyfikacja relacji, modele, hardware i software systemu diagnostycznego,* Wydawnictwo UWM, Olsztyn 2014r.
11. Michalski R., Arendt R., *Functions of a diagnostic device in a wheeled tractor, Diagnostyka, Applied Structural Health Usage and Condition Monitoring;* Olsztyn 2013 nr 4, ISSN 1641-6414.