SELECTION OF DIAGNOSTIC FUNCTIONS IN A WHEELED TRACTOR

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Summary

In a classical approach to damage diagnosis, the technical condition of an analyzed machine is identified based on the measured symptoms, such as performance, thermal state or vibration parameters. In wheeled tractor the fundamental importance has monitoring and diagnostics during exploitation concerning technical inspection and fault element localizations. The main functions of a diagnostic system are: monitoring tractor components which affect operation, safety, performance parameters and exhaust gas emissions; registering information about component damage; registering performance parameters at the moment of damage. In the paper research problem, methodology and achieved results are presented.

Keywords: wheeled tractor, algorithm, diagnostics device

DOBÓR FUNKCJI URZĄDZENIA DIAGNOSTYCZNEGO CIĄGNIKA KOŁOWEGO

Streszczenie

W klasycznych metodach diagnozowania uszkodzeń maszyn wykorzystuje się odwzorowanie stanu technicznego obserwowanej maszyny poprzez mierzony symptom np.: efektywność pracy, stan cieplny, drganiowy. W ciągniku kołowym podstawowe znaczenie ma monitorowanie i diagnozowanie w toku eksploatacji, sprowadzone do kontroli stanu technicznego i lokalizacji elementów uszkodzonych. Podstawowe funkcje urządzenia diagnostycznego to: monitorowanie elementów ciągnika kołowego mających wpływ na funkcjonowanie, bezpieczeństwo, dynamikę i poziom emisji toksycznych składników spalin; zapis informacji o uszkodzeniach elementów ciągnika; zapis informacji o parametrach ciągnika w chwili uszkodzenia. W artykule przedstawiono problem badawczy, zastosowane metody i uzyskane wyniki.

Słowa kluczowe: ciągnik kołowy, algorytm, urządzenie diagnostyczne

1. INTRODUCTION

The performance of a wheeled tractor is influenced by various factors, including the condition of mechanical, electrohydraulic and electromechanical systems which affect engine supply and the efficiency of the power transmission system. The choice of adequate steering and control methods also influences tractor operation.

Damage of complex tractor systems impairs system effectiveness, performance and operating safety. Failure mode and effects analyses as well as failure mode, effects and criticality analyses should be performed regularly in tractors to guarantee optimal performance [5, 6, 7]. Complex mechanical systems in wheeled tractors require increasingly sophisticated research methods to detect defects during design and operation.

According to Machinery Directive 93/68/EEC, a machine's technical design has to be evaluated in view of durability and susceptibility to damage. Those issues are often addressed separately at the stage of tractor design and construction due to:

- limited knowledge about modeling principles for vehicle units which are designed for operation in a changing environment,
- absence of damage analysis methods which are based on maintenance engineering,
- absence of methods for acquiring information about damage sustained during operation and the use of the resulting knowledge in machine design.

In a classical approach to damage diagnosis, the technical condition of an analyzed machine is identified based on the measured symptoms, such as performance, thermal state or vibration parameters [8]. The quality of the diagnostic process is determined by the accuracy with which damage is modeled based on the observed symptoms. They can be identified experimentally or by theoretical analysis which relies on functional models (e.g. frequency characteristics) and structural models (changes in nonlinearity, changes in weight, rigidity and attenuation parameters).

During a technical inspection, the operation and performance of a wheeled tractor is diagnosed, and the location of damaged components is identified.

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

A general structural concept of a mechatronic system in a wheeled tractor (MSDC) was proposed by [3] for diagnosing defects which affect operation, toxic gas emissions safety and performance. The structure of the MSDC [1], the damage simulation model and the diagnostic relations model were developed as part of research project No. N N504513740.

This paper discusses the main functions of a mechatronic diagnostic system in a wheeled tractor, the relations between system elements, types of diagnostic algorithms and a data communication system with a data bus.

2. SPECIFICATION

A mechatronic diagnostic system of a wheeled tractor (MSDC) can be represented by the following relationship:

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

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:

$$\text{PD} = [E_d, C_d, S, M_d, I_ż, O_p, A_d, R_d], \quad (2)$$

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,
$I_ż$ – system for the visualization of diagnostic data,
O_p – software,
A_d – 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).

The list of parameters monitored by a wheeled tractor's diagnostic system is presented in Table 1.

Table 1. Diagnostic parameters of a wheeled tractor

No.	Subassembly	Diagnostic parameter X(t)
1.	Engine	T_c – 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_{oil} – engine oil temperature Engine oil temperature is measured directly by a sensor installed in the lubrication system. $T_{oil} > T_{oil\max}$ 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_{ex1} – exhaust gas temperature in cylinder 1, T_{ex2} – exhaust gas temperature in cylinder 2, T_{ex3} – exhaust gas temperature in cylinder 3, T_{ex4} – exhaust gas temperature in cylinder 4. Exhaust gas temperature is measured by sensors installed in the exhaust manifold by every cylinder.

		$T_{exi} > 1.15 \cdot T_{exavr}$ or $T_{exi} < 0.85 \cdot T_{exavr}$, where: $T_{exavr} = \frac{1}{j}\sum_{i=1}^{j} T_{exi}$ indicates injector system failure or abnormal pressure in the i[th] cylinder. p_{oil} – oil pressure. Oil pressure is measured directly by the pressure sensor. $p_{oil} > p_{oil\max}$ is indicative of: - oil pump failure. $p_{oil} < p_{oil\min}$ indicates: - oil pump failure, - low oil level, - oil leak, - inadequate oil parameters, - significant fuel or coolant leak into engine oil, - main bearing failure, - oil filter blockage. p_{sm} – suction manifold pressure. Pressure is measured directly by a sensor in the engine's suction manifold. $p_{sm} < p_{sm\min}$ indicates: - air filter blockage, - blockage of the air supply conduit. n_{eng} – crankshaft speed. a_{eng} – engine vibration level. Engine vibration levels are measured directly by a biaxial vibration sensor. $a_{eng} > a_{eng\max}$ is indicative of engine failure. N_e – power measurement. M_e – torque measurement. MECHANICAL METHOD: 1. $V = \frac{\Pi\, n_k\, r_d}{30}$ [m/s]. 2. $a = \frac{\Delta V}{\Delta t}$ [m/s^2]. 3. $F = m\, a$ [N]. 4. $N = F\, V$ [kW]. 5. $M_s = \frac{F\, r_d}{i\, \eta}$ [Nm]. $i = \frac{\Pi\, r_d\, n_{eng}}{30 V}$, where: r_d – rolling radius, n_{eng} – engine speed, i – overall gear ratio, Power and torque characteristics as a function of speed.
2.	Gearbox	a_{gbx} – vibration levels in gearbox and reduction gear. Vibration levels are measured directly by a biaxial vibration sensor installed on gearbox housing. $a_{gbx} > a_{gbx\max}$ is indicative of gearbox or reduction gear failure. T_{gbx} – gearbox temperature. Gearbox temperature is measured directly by a sensor installed on gearbox housing. $T_{gbx} > T_{gbx\max}$ indicates gearbox failure or low gearbox oil level.
3.	Reduction gear	a_{rgx} – vibration levels in gearbox and reduction gear. Vibration levels are measured directly by a biaxial vibration sensor installed on gearbox housing. $a_{rgx} > a_{rgx\max}$ is indicative of gearbox or reduction gear failure. T_{rgx} – reduction gear temperature. Reduction gear temperature is measured directly by a sensor installed on gearbox housing. $T_{rgx} > T_{rgx\max}$ indicates reduction gear failure or low oil level in reduction gear.
4.	Final drive and	a_{fd} – vibration level in final drive. Vibration levels are measured directly by a biaxial vibration sensor installed in the final

	differential	drive. $a_{fd} > a_{fd\max}$ is indicative of final drive failure. T_{fd} – final drive temperature. Final drive temperature is measured directly by a sensor installed on final drive housing. $T_{fd} > T_{fd\max}$ is indicative of final drive failure or low oil level in the final drive.
5.	Left hub reduction gear	n_{rgl} – left wheel speed. Wheel speed is measured directly by a speed sensor. When the differential is locked and the clutch is disengaged, $n_{rgl} < \frac{n_{eng}}{i}$ is indicative of power transmission failure.
6.	Right hub reduction gear	n_{rgr} – right wheel speed. Wheel speed is measured directly by a speed sensor. When the differential is locked and the clutch is disengaged, $n_{rgr} < \frac{n_{eng}}{i}$ is indicative of power transmission failure.
7.	Steering system	φ_{sa} – steering angle. The steering system's response to a given wheel angle is determined.
8.	Braking system	S_{bl} – distance between brake shoes in the left wheel. S_{br} – distance between brake shoes in the right wheel. The distance between brake shoes is measured directly by distance sensors. $s_{bl} \le s_{bl\min}$ or $s_{br} \le s_{br\min}$ is indicative of break shoe failure.
9.	Location	α – vehicle tilt angle. The tilt angle is measured directly by an inclinometer.
10.	Front axle wheels	n_{fwr} – right wheel speed. n_{fwl} – left wheel speed. s_{fw} – relative slip of drive wheels (indirect measurement). Rotational speed of rear right n_{wr} and left n_{wl} wheels. s_{rel} – relative slip of rear wheels [%] (indirect measurement); if $n_{fwl} + n_{fwr} < n_{rgl} + n_{rgr}$, then $s_{rel} = \left(\frac{n_{fwl} + n_{fwr}}{n_{rgl} + n_{rgr}} - 1\right) \cdot 100\%$ if $n_{fwl} + n_{fwr} \ge n_{rgl} + n_{rgr}$, then $s_{rel} = 0\%$ Determination of slip based on GPS data: $\omega = \frac{2\pi \cdot n_{eng}}{60}$ – angular velocity, V – vehicle speed given by GPS receiver, $\omega \cdot R$ - wheel circumferential speed, $s = \frac{V - \omega \cdot R}{V}$, $s > 0$ - braking slip, $s < 0$ - acceleration slip, $s = 0$ - slip-free driving, $s = 1$ - wheel lock.

3. DIAGNOSTIC SYSTEM HARDWARE

The key component of the proposed diagnostic system (Fig. 1) is an on-board computer in shock and vibration-proof housing, with a touch screen and passive cooling. The computer is connected to a USB/DeviceNet protocol converter (extended CAN protocol) via the USB port. The CAN bus connects the interface module with three slave devices collecting data from sensors installed in various locations of a wheeled tractor. Every module has a unique ID and an individual data processing mode. Data transmission speed in the CAN network with the DeviceNet protocol reaches 500kb/s.

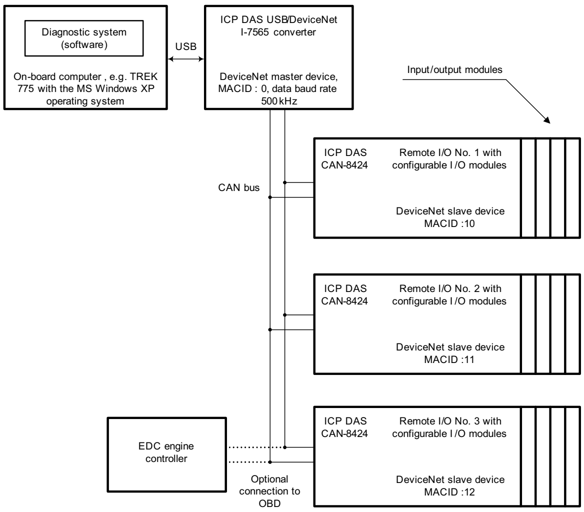

Fig. 1. Structure of the computer subsystem in a diagnostic device

The first I/O module has the highest data acquisition speed, and it supports rotational speed sensors (pick-up pulse sensors) and acceleration sensors which diagnose vibration levels in a tractor. The first I/O module also collects information about the instantaneous position of a rotating shaft and control voltage for electrostatic injector valves in the CommonRail system.

The second I/O module has low (average) data acquisition speed. It collects information about the following operating parameters: pressure, fluid levels, voltage and current values. One of the four module cards controls actuating elements during the performance of test programs and during failures.

The third I/O module has low data acquisition speed. It supports temperature sensors (Pt-100) in selected engine locations and exhaust gas temperature sensors (thermocouple sensors) in each cylinder. Due to low variations in time constants, measurements are repeated up to several times per second. One of the module cards diagnoses voltage and current data in electrical circuits.

4. DIAGNOSTIC SYSTEM SOFTWARE

The system operates in the Windows XP (optionally Win98/Win2000/WinNT) environment. A corresponding driver has to be installed for the USB/DeviceNet converter. A special application has been developed for the DeviceNet device in the

Windows environment for configuring the inputs and outputs of all extension modules (Fig. 2).

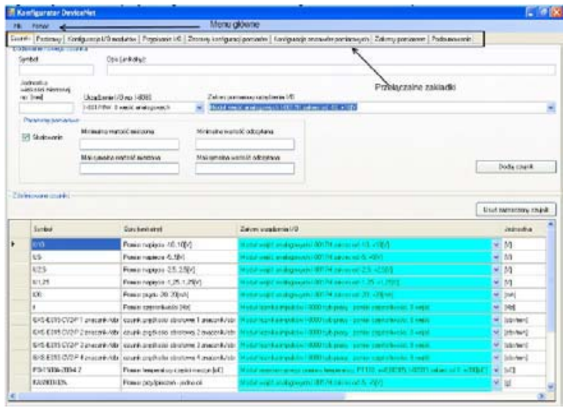

Fig. 2. Main window f the KONFIGURATOR application

The KONFIGURATOR application creates and saves files (XML and XSD) which describe the structure of the DeviceNet network based on ICP DAS CAN-8424 slave devices and an ICP DAS DeviceNet I-7565-DNM master device. Configuration data and the remaining information is saved in XML files. XML files contain data, whereas data structure is written in XSD files. XML and XSD are text files which can be viewed in any text editor such as the notepad. Configuration data used in the measurement system is also registered, including the type of I/O devices (voltage, current, frequency input and output signals) installed in CAN-8424 slots. Device inputs are configurable. The main configuration parameter is the measurement range which is set for all system inputs. Additional parameters are collected from external devices connected to I/O modules. The application has been developed for a linear data processing system.

Additional information includes: measurement kits identifying I/O devices which are installed in slots and which participate in a given measurement within the set time intervals (measurement frequency). The automatic measurement option is activated in a given measurement kit to identify the I/O device and measurement frequency. The following measurement kits can be developed for different diagnostic strategies:

- standard kits for detecting failures,
- dedicated kits for identifying possible defects, activated when failure of a tractor element or subassembly is suspected.

DeviceNet hardware of the proposed system is presented in Fig. 1. A mechatronic diagnostic system collects and processes data in real time. The diagnostic device collects and processes data at time intervals *T*, it computes state variables for the applied models, activates diagnostic procedures, the keyboard operating procedure and diagnostic signal circuits. Real-time operation implies that the total computer operating time dedicated to data acquisition and other processes is shorter than the adopted time interval *T*.The purpose and priority of procedures in the software developed for the diagnostic device is presented in Table 2.

Table 2. Diagnostic software procedures

No.	Procedure	Priority
1.	Collection of measurement data, generation of control signals	I
2.	Keyboard (touch screen) operation, program switching to dedicated diagnostic procedures	II
3.	Fast Fourier Transform (FFT)	III
4.	Determination of angular acceleration of the crankshaft	IV
5.	Determination of selected state variables of diagnostic models	V
6.	Diagnostic procedures	VI
7.	Diagnostic state signaling	VII
8.	Other procedures	VIII

Data collection and control signal generation procedures have the highest priority, and they are initiated by a signal from the computer clock. A signal from the internal clock interrupts all lower priority procedures and initiates data collection. The diagnostic device operates at time intervals T (default value = 1 s) and selected measurements and numerical calculations are performed cyclically. The time interval is set in view of the number and frequency of measurements, data transmission speed in the CAN network, the number and complexity of diagnostic procedures.

After moment t_k, the procedure of cyclic data readout from the first module is initiated, and data is collected from speed sensors, shaft position sensors, acceleration sensors and injector valve voltage sensors (cyclic message ID-I). An n number of moments t_1, t_2, t_3 … during which measurement parameters are read was set in interval T_I; $T_I < T$. The transmission of data from the first module is completed within approximately t_{pI} = 0.143 ms. The data acquisition process is presented in a time diagram in Fig. 3.

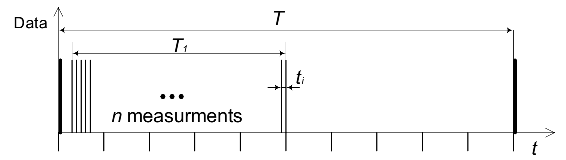

Fig. 3. Time diagram of data acquisition in a diagnostic system; bold line – overall data transmission time, thin line – time of data transmission from module I, T – time of diagnostic system operation, t_i – one cycle of data readout from module I

4. CONCLUSIONS

The discussed functions of a mechatronic diagnostic device include a set of monitored tractor elements, sensors, a system controlling the acquisition and processing of data, a system for visualizing diagnostic data, hardware and software components and diagnostic algorithms.

The key component of the proposed diagnostic system is an on-board computer with a touch screen which is connected to a USB/DeviceNet protocol converter (extended CAN protocol) via the USB port. The CAN bus connects the interface module with three slave devices collecting data from sensors installed in various locations of a wheeled tractor. Every module has a unique ID and an individual data processing mode. Data transmission speed in the CAN network with the DeviceNet protocol reaches 500kb/s.

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