Functional structure of diagnostic system for wheeled tractors

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Abstract: An application of computer controlled fuel injection systems in vehicle engines and growing demands concerning toxic substances emission and fuel consumption was a main reason for OBD (On Board Diagnosis) development. In spite of a great technological development, only some tractors are equipped in diagnostic systems. On board diagnosis is strongly connected with emission demands and does not concern other important vehicle functions. In the developed mechatronic diagnostic system, based on generated consequences, four groups of defects are accepted: functional (u_f), which inhibit performance, exhaust (u_e), which causes increase toxic emissions, that jeopardize driving safety (u_s) and defects that affect engine performance (u_d). The diagnostic system consists of a board computer with specialized programs, acquisition data modules working in CAN net with protocol DeviceNet, measuring sensors and actuators. In the paper accepted assumptions, and a structure of mechatronic system model and organization of a diagnostic program are presented.

Keywords: mechatronic, diagnostic systems, tractors, OBD – On Board Diagnostic

1. Introduction

Devices monitoring combustion process in cars and other vehicles are by ecological demands obligatory introduced. Accepted legal rules oblige vehicle producers to equip cars (trucks) in developed on board diagnostic systems, depending on region called: OBD II (USA), EOBD (European Union), JOBD (Japan). A system OBD (On Board Diagnostic) defines a set of diagnostic procedures, enable early identification of faults, which can causing toxic substances emission in exhaust gases [5].

Actually a problem of wheeled tractors diagnostic is realized by a periodical technical inspection using stationary diagnostic stands in vehicle inspection services. During exploitation only some functional parameters are monitored. On board diagnostic systems, used only in some tractors, find an implementation in computer controlled combustion process vehicles. In this case the diagnostic is only an additional process absorbing free calculation power of the computer, using sensors applied for combustion process control [9]. We can state, that tractor diagnostic is limited to check an activity of electronic systems (easy measurement), neglecting possible mechanical causes of malfunction tractor's work [7].

A wheeled tractor can perform different functions, depending on requirement. Applied technical diagnostic is a vital tool for assessing:
- functionality during transport and operation,
- performance parameters,
- operating safety in field and road driving modes,
- exhaust gas emissions.

A developed mechatronic diagnostic system of wheeled tractors enables monitoring and diagnosing i.e. quality inspection and localization of fault elements during exploitation. We assumed a possibility of detection and localization of faults, based on generated consequences, divided into the following groups:
- functional defects (u_f), which inhibit performance (torque, towing force, working speed, fuel consumption);
- exhaust defects (u_e), which increase toxic emissions (and noise) and fuel consumption due to a malfunction of the fuel supply system, layout of the Diesel engine and the power transmission system;
- defects that jeopardize driving safety (u_s) can affect the following tractor systems: brake, suspension, steering and lights;
- defects that affect engine performance (u_d) and driving parameters in a tractor, including decreased response to changes in movement parameters, unequal power levels, significant loss of power and moment of force.

In the paper accepted assumptions, general structure of the mechatronic system and preliminary organization of diagnostic programs are presented.

2. Measurement of tractor parameters

The mechatronic diagnostic system of wheeled tractors will be a base for further prototypes of testing devices development. At current stage of investigations following assumptions concerning parameter measurements of a tractor are accepted:
- significant element of a tractor is Diesel engine, and its work should be monitored by diagnostic system;
- an important element of tractor is power transmission system;
- we should consider a set of subsystems (elements) directly influencing safety of a traffic.

Measurement of the following parameters of Diesel engine is accepted:
- temperature of: cooling fluid, lubricating oil and chosen points of the engine;
- temperature of exhaust gases of cylinders;
- lubricating oil level;
- lubricating oil pressure;
- intake manifold vacuum of turbocharger;
- acceleration of engine body for vibration diagnostic;
- control voltage of injector valves in CommonRail system.

In power transmission system angle speed of shafts ω_i is measured (fig. 1). Additionally a placement of engine shaft φ is measured.

We consider measurements of the following parameter influencing a traffic safety:
- steering play of kinematic pairs (an angle of steering wheel measurement);
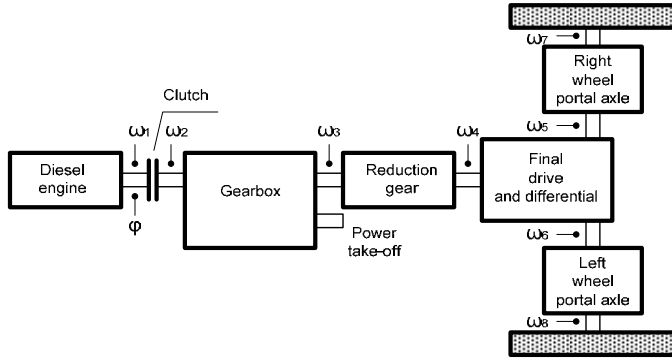- air pressure in wheels;

Fig. 1. Measurements of wheeled tractor's power transmission system
Rys. 1. Pomiary układu napędowego ciągnika kołowego

– wear of friction linings of vehicle brakes (distance sensors);
– current flow and voltage; diagnostic of: head-lights, wind-screen wipers and other electric devices;
– deviation of vehicle in X-Y axes (inclinometer);
– level and pressure of brake fluid.

3. Hardware structure of the diagnostic system

A basic element of the diagnostic system (fig. 2) is a board computer, vibration and shock resistant, with a touch screen and passive cooling.

The computer is connected by USB port with Device-Net master device (DeviceNet is a network protocols based on a CAN bus). The CAN bus connects master board with three slave devices – modules of data acquisition from chosen points of tractor. Each module is distinguished by node address (MAC ID) and works with different data acquisition mode. The remote I/O unit (slave device) has 4 expansion slots equipped with 4 input (output) cards, appropriate chosen for ranges and types of measured signals [1]. In the CAN bus a speed of data transmission is high – baud rate is 500 kb/s.

The I I/O unit works with the greatest data acquisition speed and serves sensors of measures of dynamic proces-
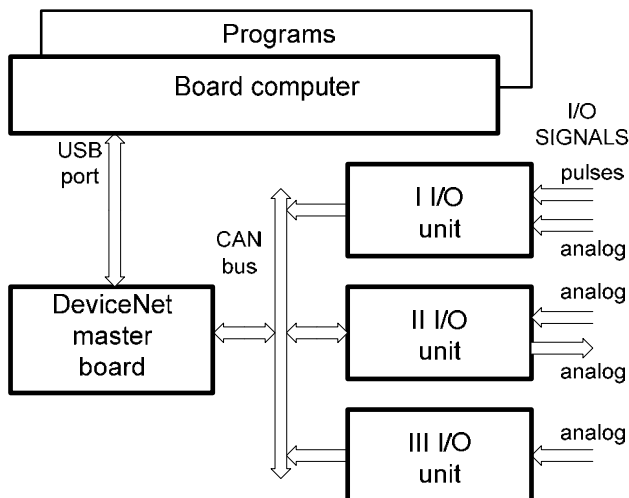
ses – of shaft angle speeds (pulse sensors pick up) and acceleration sensors for vibration diagnostic of tractor. The unit also gathers data describing angle placement of engine shaft and voltages controlling injector valves in CommonRail system.

The II I/O unit works with slow (medium) speed of data acquisition. It gathers data concerning: pressures, fluid levels in tanks, currents and voltages. One of 4 cards of the unit for actuators control is assigned. During realization of given diagnostic tests and in emergency conditions, output signals will control tractor subsystems.

The III I/O unit works with slow speed of data acquisition. It serves temperature (Pt 100) sensors located in chosen points of engine body and temperature sensors (thermocouples) placed in exhaust manifold near each cylinder. Depending on a great time constants a period of measure cycles can be large – near 1 s. One of cards of III unit, for diagnostic of voltage presences and current flows is used.

4. The diagnostic system's program

The system works in Windows XP environment (any windows based system Win98/Win2000/WinNT). For DeviceNet master control a proper driver should be installed.

In the mechatronic diagnostic system data acquisition and processing should be in real time realized. The system achieve data in poll messages, at each main period of time T, processing them, calculate state variables, starts diagnostic procedures, keyboard commands and diagnostic states signalization procedures. Real time work means, that a sum of time periods of data acquisition and another procedures is less than accepted main period of the time T.

Program procedures of the diagnostic system, their destination and realization priority in table 1 are presented.

Tab. 1. Program procedures of the diagnostic system
Tab. 1. Procedury systemu diagnostycznego

| L.p.	Procedure	Priority
1.	Data acquisition and control procedure	I
2.	Starting keyboard (touch screen) and specialized diagnostic procedures	II
3.	Fast Fourier Transformation (FFT) procedure	III
4.	Procedure calculating angle acceleration of an engine shaft	IV
5.	Procedure calculating chosen state variables of diagnostic models	V
6.	Diagnostic procedures	VI
7.	Diagnostic states signalization procedure	VII
8.	Another procedures	VIII

Data acquisition and control procedures have the highest priority of execution and by internal computer clock are controlled. Computer clock signal interrupts all calculations of lower level procedures and starts data acquisition process. The main time interval $T = 1$ s (actually) of the diagnostic system work is accepted – poll massages of all data measure-

Fig. 2. The structure of diagnostic system hardware
Rys. 2. Struktura systemu diagnostycznego

ments and realization of all assumed calculations. The main time interval depend on a number and frequency of realized measurements, baud rate of data in CAN net and a number and complexity of the diagnostic procedures.

The following methods of data message transfers are accepted: each T poll message addressed to all units (poll message ID-I, ID-II, ID-III) is transmitted. A number of transmitted bytes of data is 3 units × 64 bytes = 192 bytes. In DeviceNet protocol, for each 8 bytes of frame the useful content is at least 7 bytes.

We should send each 1 s $(8/7) \times 192$ data bytes with baud rate 500 kb/s (a distance is not large). A time of data transmission is $t_p = (8/7)\ 192/500\ \text{ms} = 0.429\ \text{ms}$. The time of data transmission for CAN net is very short and we can effective control the realization of data acquisition.

After t_k cyclic message data transfer procedure of unit I is started – data of: shaft angle speeds and placements, accelerations and voltages controlling injectors. In period of the time T_1; $T_1 < T$, n moments of data messages: t_1, t_2, t_3 ... are appointed. Transferred data describe dynamic processes of wheeled tractor. A time of each whole data transmission of unit I is about $t_{pI} = 0.143$ ms. In time diagram (fig. 3), accepted data acquisition is presented.
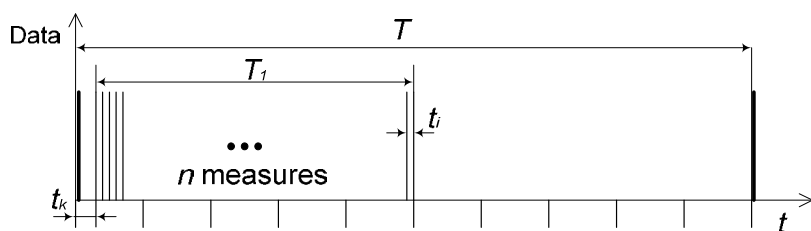
Fig. 3. Time diagram of data acquisition in diagnostic system; bold line – time of whole poll data transfer, normal line a time of data transfer from unit I, T – main period of work of the diagnostic system, T_1 – period of cyclic data transfer of dynamic processes, t_i – period of one cycle data transfer from unit I

Rys. 3. Diagram czasowy akwizycji danych w systemie diagnostycznym; gruba linia – czas przesyłania wszystkich dostępnych danych, cienka linia – czas przesyłania danych modułu I, T – okres pracy systemu diagnostycznego, T_1 – okres cyklicznego zbierania danych procesów dynamicznych, t_i – okres jednego cyklu zbierania danych z modułu I

The most number of data is necessary for frequency analysis of acceleration of engine body (vibration diagnostic). The period T_1 appoints the smallest analyzed spectrum frequency and period of cycle data acquisition t_i appoints the highest spectrum frequency [2].

In the mechatronic diagnostics system, following assumptions concerning realized measures are accepted:
- poll input data with period T:
  - angle speed of wheels and shafts (up to 20 measures);
  - placement of engine shaft (1);
  - power transmission system temperature (10);
  - exhaust gases temperature (8);

- fluids level (3);
- tires pressure (4);
- intake manifold vacuum (2);
- oil and brake fluid pressure (2);
- brake jaw gap (4);
- vehicle inclination (2);
- current flow (30).
- cyclic input data each t_i, in time period T_1:
  - chosen angle speeds of wheels and shafts (up to 20 measures);
  - placement of engine shaft (1);
  - engine vibrations (1);
  - voltage of injector valves (up to 8).
- measures performed as special diagnostic test:
  - back lash of steering wheel measure (1).

The end of the dynamic processes data transfer starts fast Fourier transformation procedure – calculation of vibrations spectrum. Parameters of the spectrum are in diagnostic procedures used.

After spectrum calculations a dependence of angle speed and engine shaft placement in function of time is calculated. Similarly a function of injector valves control and shaft placement depending on time is created.

Procedures calculating chosen state variables can concern: output variable of given process, state variable (the variable inaccessible for direct measure). In the first case, comparison of measured value (output variable) with modeled value (a pattern) gives us diagnostic information. In the second case, calculated state variable replaces measured data [3, 4, 8].

At development of the diagnostic system following definition is accepted: a failure is every event which deteriorates a tractor's performance quality and effectiveness, and which should be detected in the diagnostic process [6].

A tractor's fault S_N results from one of the four defect classes $\{u_f,\ u_e,\ u_s,\ u_d\}$, what we can express in the form of the following relation (1):

$$S_N \Rightarrow \{u_f \cup u_e \cup u_s \cup u_d\} \neq 0 \qquad (1)$$

Diagnostic knowledge is composed of facts, relations and procedures. In a mathematical approach, the diagnostic pro-
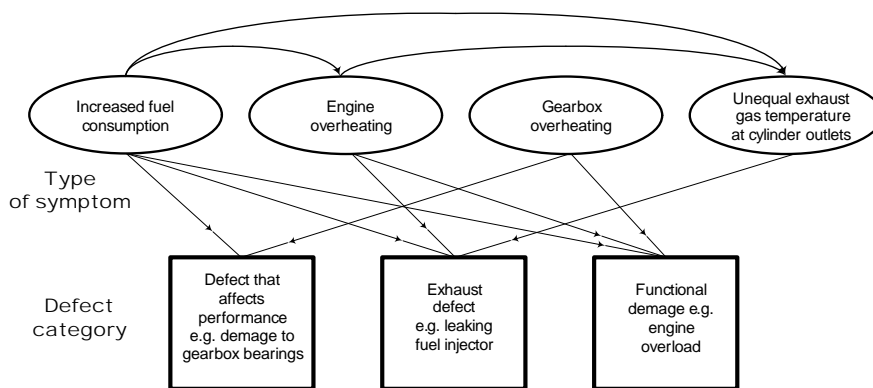
Fig. 4. Diagram illustrating the relation between defects and symptoms

Rys. 4. Ilustracja zachodzących relacji między symptomami a uszkodzeniami

cess involves the search of relations R between defects (faults) and specific diagnostic symptoms. There exist cause and effect relationships between malfunction $f_i \subset F$ of tractor components and symptoms s_j represented by set S. This relationship can take on one of the following forms (2) and (3):

$$R : \{s_j\} \Rightarrow f_i \,, \qquad (2)$$

$$R : \{s_j\} \Rightarrow \{f_i\} \qquad (3)$$

The form (2) is one-to-one relationship (a set of symptoms identifies a given state); the form (3) is one-to-many relationship.

For diagnostic purposes we can describe existing relations between states of tractor and state variables modeling given processes. Relation R_{XF} can be described by the Cartesian product of sets F and X:

$$R_{XF} \subset X \times F \,, \qquad (4)$$

where: X – set of process variables, F – machine's state space.

An example of relations between defects and symptoms is presented in fig. 4.

Diagnostic relation evaluation of wheeled tractor, considering accepted defect classes requires investigations. Currently in the diagnostic procedures, checking simple relations of inclusion of chosen state variables set in permissible range of parameters is accepted.

5. Remarque and conclusions

Actual works concerning development of the mechatronic diagnostic system of wheeled tractors are writing and testing computer programs. The system of data acquisition on three slave CAN8424 units with measuring cards and master unit ICP DAS production is based.

In next stage of development of the diagnostic system we install it on a chosen type of tractor. First test will be carried on using a diagnostic stand. The tests will be base for diagnostic relations evaluation and applied models verification.

The technical diagnostic system oriented on four classes of defect identification is an original solution. Standard diagnostic of wheeled tractors regards only evaluation of basic work parameters of an engine and chosen units and is limited to parameter monitoring, which are necessary for the engine control. Standard OBD II system detects malfunction only when the measured value exceeds the standard value by 50 % [5].

Acknowledgements

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Struktura funkcjonalna systemu diagnostycznego ciągnika kołowego

Streszczenie: Mimo dużego rozwoju technologicznego, tylko niektóre ciągniki kołowe są wyposażone w systemy diagnostyczne. Aktualnie stosowana diagnostyka pokładowa pojazdów jest silnie związana z wymaganiami emisyjnymi i nie obejmuje innych ważnych funkcji pojazdu. W tworzonym mechatronicznym systemie diagnostycznym ciągnika kołowego ze względu na możliwe skutki przyjęto cztery grupy uszkodzeń: funkcjonalne (u_f) powodujące ograniczenie efektywności pracy, emisyjne (u_e) wywołujące wzrost emisji związków toksycznych, zagrażające bezpieczeństwu ruchu (u_s) ciągnika oraz pogarszające jego dynamikę (u_d). System diagnostyczny tworzy komputer pokładowy z wyspecjalizowanym oprogramowaniem, moduły akwizycji danych pracujące w sieci CAN z protokołem DeviceNet, czujniki pomiarowe (sensory) oraz elementy wykonawcze (aktuatory). W artykule przedstawiono przyjęte założenia, budowę modelu systemu mechatronicznego oraz organizację programu diagnostycznego.

Słowa kluczowe: mechatronika, system diagnostyczny, ciągnik kołowy, diagnostyka pokładowa

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