METHOD OF DIAGNOSING THE POWER TRANSMISSION SYSTEM IN A TARPAN HONKER MILITARY VEHICLE[1]

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Abstract

   This paper presents a diagnostic system for monitoring the operation of the Tarpan Honker military vehicle, referred to as the Autonomous Logistics System (ALS). The diagnostic model, the structure and tasks of ALS and selected diagnostic algorithms were discussed. The structure of the diagnostic system was analyzed in detail with special emphasis on communication between system modules. The description of the diagnostic model defines diagnostic monitors implemented in the memory of the on-board diagnostic system. The ALS system comprises transmission-receiver modules connected as part of an RS-485 type communication and data transmission system. The modules were individually designed and provided with measuring sensors using multipin plugs and connectors. All measuring sensors were installed in the vehicle, and most of them were not part of built-in equipment. Every module has a diagnostic connection for entering data into processor memory (programming) and for module self-testing. The implemented system is fully independent of external circuits, therefore, if damaged or not activated, it does not affect mission performance.

Keywords: transport, diagnostics, transmission system, transmission topology, RS-485

1. Introduction

   The contemporary battlefield is characterized by dynamic operational, tactical and technical requirements. Those requirements are met through the acquisition of real time data, high operational and tactical mobility of troops and warfare, distribution and movement in terrain, maneuverability performance and safe combat operations under all circumstances and at all times.

   Contemporary combat requirements necessitate the choice of modern warfare and military equipment, in particular vehicles with effective operating and diagnostic systems. The contemporary military vehicle should be prepared for network-centric warfare [7], therefore, it has to meet the highest reliability and safety standards. Damage resistance is one of the key criteria in evaluations of a military vehicle's reliability and safety.

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2. Diagnostic model of the power transmission system in a military vehicle

The functionality of a military vehicle is described by a set of tasks which have to be performed under all circumstances, both outdoors and in the battlefield. The vehicle's objective function should be determined to indicate whether the vehicle's current technical condition supports the achievement of planned tasks.

According to [3], the objective function of a military vehicle is defined as a specific interaction between the following variables: H_o – transformation vector, $U(t)$ – input signal vector, $X(t)$ – status parameter vector, t – dynamic time, and Θ - operating parameters. The number of input functions ($U(t)=const$) is strictly defined in diagnostic tests to ensure that every change in diagnostic signal results from changes in the vehicle's technical condition.

In tests analyzing the technical condition of mechanical vehicles, state vector $W(t)$ can be determined by measuring the components of vector $Y(t)$ of diagnostic signals. In simple terms, the state vector is a function of independent and complete numerical values of diagnostic parameters (status parameters) and the transformation operator [6].

The Tarpan Honker military vehicle was analyzed to diagnose, prognosticate and generate its operating states [5]. As part of the diagnostic process, the power transmission system of the military vehicle was split into five decomposition levels. The 5-level structural model of the investigated vehicle is discussed in [4]. A homogenous 5-level structural model of the studied vehicle has been developed. Level 5 combines basic components, and it describes the depth of structural penetration. Damage localization takes place at level 5. A set of basic components has been created on the assumption that a diagnosis of all vehicle elements is possible but not justified. The set accounts for basic components which, in the authors' opinion, need be diagnosed to determine the vehicle's general ability to perform a combat mission. The methodology for developing vectors of diagnostic parameters, describing information models and their characteristics is presented in [1, 4]. In the modeled diagnostic system, faults are identified in a binary classification system which is identical for all symptoms.

Diagnostic algorithms

Diagnostic algorithms are core concepts in technical diagnostics. In the discussed system, they are referred to as diagnostic tests which analyze the operation of diagnostic system components:
−   operability test of electric measuring and actuating elements,
−   passive test of metrological traceability of actuating elements,
−   functional tests of actuating elements,
−   active tests of metrological traceability of measuring elements.

In measuring and actuating elements, algorithms of electrical operability are applied to analyze: circuit continuity, short circuit of the signal line and actuating elements to ground or supply voltage. A passive algorithm for evaluating measuring elements tests the accuracy of sensor readouts. A functional algorithm uses a model signal to test actuating elements. An active algorithm for testing the metrological traceability of measuring elements is similar to a functional algorithm. In an active test, the control signal is used to analyze the actuating element by monitoring changes in measured values.

The developed system relies on diagnostic algorithms (tests) where the operability criterion has been formulated as follows:

An element or a system is regarded as damaged if its characteristic parameter or diagnostic signal (symptom/s) exceed boundary values or allowable values, thus obstructing or disabling task performance. The element is regarded as operational if the above requirements are not met.

In this paper, diagnostic tests (algorithms) are referred to as monitors based on standard OBD-I [2]. Every monitor (algorithm, test) supports only one system which affects vehicle operation and

task performance. The monitors implemented in the on-board diagnostic system have been classified as follows (Tab. 1.2):

- discontinuous (conditional) monitors which require the implementation of other monitors and/or prolonged observations of changes in parameter values under given driving conditions, i.e. temperature, dynamic behavior of the engine and the power transmission system;
- continuous (unconditional) monitors which support elements that can be tested under any driving conditions and whose performance is not dependent on testing requirements for other monitors.

A model for communicating the status of selected subassemblies of the power transmission system and the accompanying fault symptoms, without identifying boundary and admissible states, is presented in Tab. 1.1.

Tab. 1.1. Diagnostic information model for identifying the status of selected elements of the power transmission system based on registered symptoms, without identifying boundary states

Subassembly	State (W_m)	Symptoms (Y_n)
Gearbox + reduction gear	$W_{3,1}$ – gearbox and reduction gear are operational	not ($W_{3,2}$), not ($W_{3,3}$) and not ($W_{3,4}$)
	$W_{3,2}$ – excessive wear of gearbox, reduction gear or clamping mechanisms	contact shorting in a binary vibration sensor of the gearbox and reduction gear after an n number of gear shifts (checked 1-2 s after gear shift) (signal S_6)
	$W_{3,3}$ – low oil or seizure of gearbox or reduction gear elements	$T_{sb-r} \geq T_{gr3}$ where: T_{sb-r} – temperature of gearbox and reduction gear [°C] T_{gr3} – boundary temperature of gearbox and reduction gear [°C]
	$W_{3,4}$ – damaged elements of gearbox, reduction gear or clutch	open contact in the gear shift position sensor (signal S_3)
		open contact in the gearbox clearance sensor (signal S_4)
		$n_e > 0$ where: n_e – rotational speed of crankshaft [rpm]
		$n_r = 0$ where: n_r – rotational speed at reduction gear outlet [rpm]

The discussed diagnostic system was equipped with diagnostic monitors. A list of monitors and monitor types are presented in Table 1.2.

Tab. 1.2. List of diagnostic monitors implemented in the memory of the diagnostic system of the Tarpan Honker military vehicle

No.	Diagnostic monitor	Type / Description
1	Circuit temperature monitor	continuous – for determining boundary and admissible temperatures of operating systems and materials
2	Fluid level monitor	continuous – for determining operating fluid levels
3	Engine cooling monitor	discontinuous – for determining engine temperature at low driving speeds
4	Battery and electrical installation monitor	discontinuous – for determining battery status, charging parameters and electrical installation status
5	Fuel consumption monitor	continuous – for determining fuel consumption and driving distance on current fuel reserve
6	Engine power monitor	discontinuous – for determining instantaneous engine power
7	Power transmission system monitor	discontinuous – for determining wear/clearance of the power transmission system (clutch, gear box, reduction gear, crankshaft, final drive) and transmission clamp damage
8	Monitor of front axle wheel spin	continuous – for determining the relative spin of front axis wheels
9	Monitor of rear axle wheel spin	continuous – for determining the relative spin of rear axis wheels
10	Tire pressure monitor	discontinuous – for determining the loss of tire pressure
11	Power transmission system efficiency monitor (gear shift assistant)	continuous – for optimizing the gear-shifting sequence subject to crankshaft load

3. Structure of the diagnostic system

The communication and data transmission system in the discussed monitoring and diagnostic system relies on an RS-485 type transmission system with linear (serial) half-duplex technology. The receiver and the transmitter communicate as follows: the transmitter has differential output voltage of minimum 1.5 V, whereas the receiver picks up differential signals with the minimum value of 200mV (Fig. 1). Those values guarantee reliable transmissions, even if significant signal loss is reported along different components of the transmission path.

The functional structure of the developed diagnostic system and data transmission topology are presented in Figure 1. The data transmission structure relies on the RS-485 standards for which four receiver modules (modules No. 1, 2, 3 and 4) and one receiver-transmission module (module No. 5) have been designed.
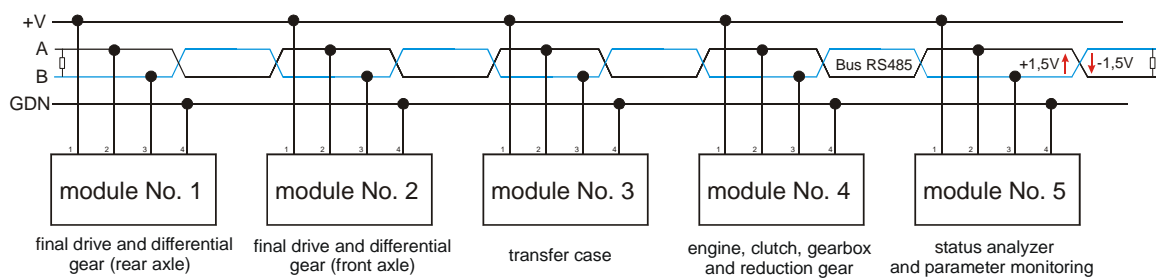

Fig. 1. Functional structure of the diagnostic system and the data transmission system with an indication of the main system components, +V – 12 V power supply, GDN – ground, A, B – RS485 bus signal line

The structure of the above modules relies on the Atmega 250 8-bit control processor with 256 kB memory and 16 MHz clock rate.

RS-485 is a standard data transmission system designed for multipoint transmission lines (Fig. 1). Unlike other standards, RS-485 defines and limits only the electrical characteristics of the transmitters and receivers connected to a shared data bus. Based on the data (information) supplied by the internal protocol (RS 485 standard), each module (receiver and transmitter) generates an electrical signal which is transmitted to the data bus (data bus bar or data transmission network). In the designed system, data is transmitted to the data bus every 250 ms. According to the authors, in the monitored systems, this time interval is sufficient to identify the fault and the observed parameters. According to estimates, the computing power of the Atmega2560 control processor in each module will be deployed in 50%.

The data protocol generated by any module connected to the bus is fed to both bus cables (Fig. 1) with opposing signals to protect the signal from interruptions caused by other electrical devices or magnetic fields. The data transmission protocol comprises several fields (data frames). A graphic interpretation of the data protocol for module No. 1 is presented in Figure 2.
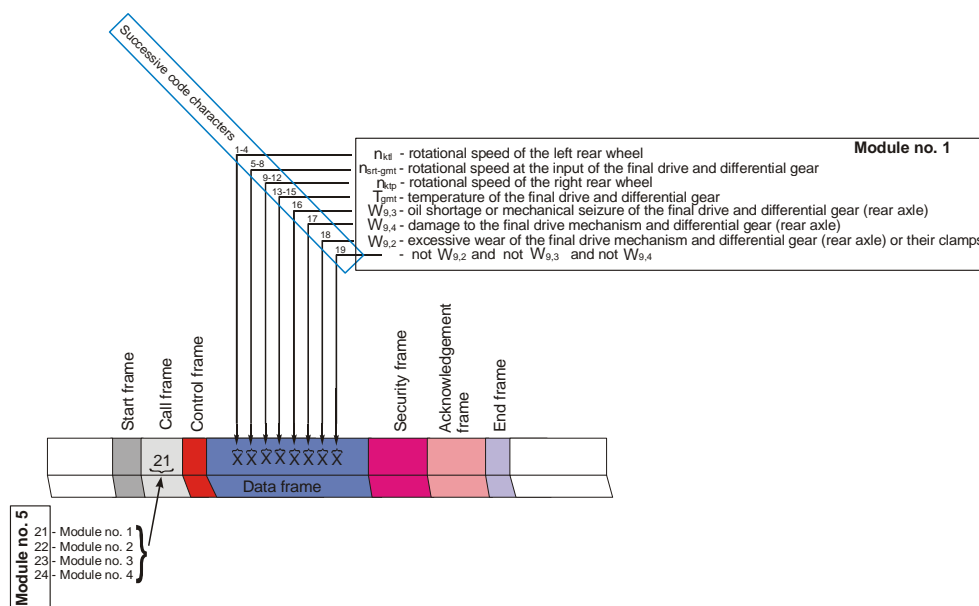

Successive code characters

n_{kfl} - rotational speed of the left rear wheel
$n_{srt-gmt}$ - rotational speed at the input of the final drive and differential gear
n_{ktp} - rotational speed of the right rear wheel
T_{gmt} - temperature of the final drive and differential gear
$W_{9,3}$ - oil shortage or mechanical seizure of the final drive and differential gear (rear axle)
$W_{9,4}$ - damage to the final drive mechanism and differential gear (rear axle)
$W_{9,2}$ - excessive wear of the final drive mechanism and differential gear (rear axle) or their clamps
   - not $W_{9,2}$ and not $W_{9,3}$ and not $W_{9,4}$

Module no. 1

Start frame | Call frame | Control frame | Security frame | Acknowledgement frame | End frame

Data frame

Module no. 5
21 - Module no. 1
22 - Module no. 2
23 - Module no. 3
24 - Module no. 4

Fig. 2. Principal structure of the data protocol generated by module No. 1 (described in the text) [4]

The information confirming that data can be transmitted to a selected module is sent via the call frame. In the analyzed example, module No. 5 fills the data frame with code "21" and sends the inquiry to module No. 1. Code "21" means that module No. 1 can transmit data, and a data frame comprising a sequence of 19 characters describing the parameters or statuses monitored by module No. 1 appears in the data signal frame. The code is encrypted by receiver-transmitter module No. 5, and the relevant information is displayed in the graphic interface. The length of the frame code is determined by the volume of data transmitted by the data frame. The frames shown in Figure 2 which are not described above are part of the internal structure of the RS-485 transmission standard, and they are not programmable.

4. Physical model of the diagnostic system

A physical model of an on-board diagnostic and monitoring system for the Tarpan Honker military vehicle, referred to as the Autonomous Logistics System (ALS v1.0), was developed. The location of actuating modules and measuring sensors in the vehicle is presented in Figure 3.
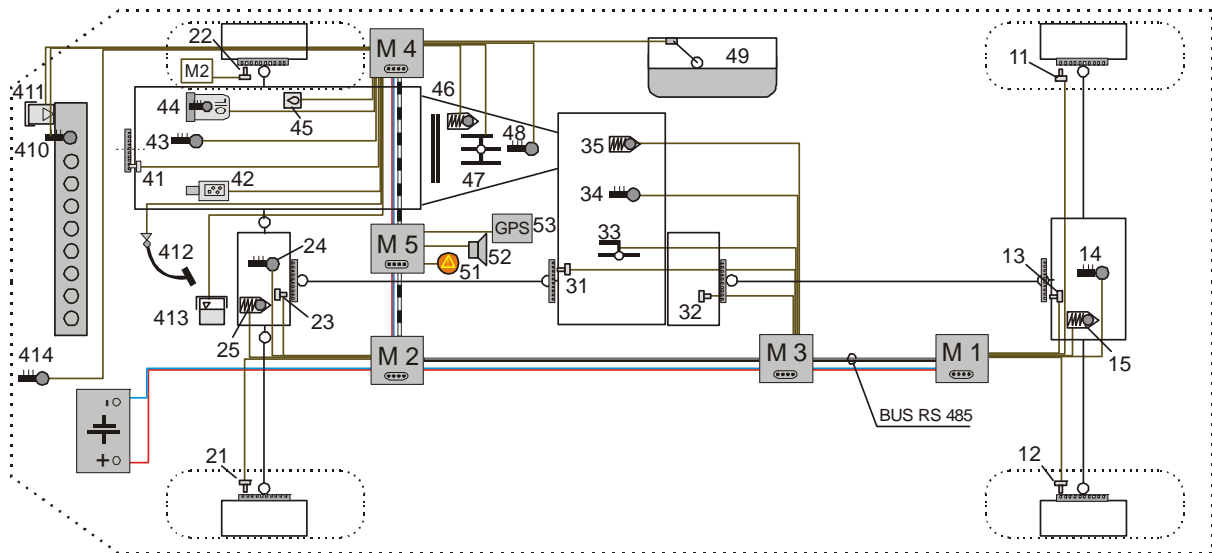
Fig. 3. Graphical presentation of the Autonomic Logistics System v. 1.0. M1 in the Tarpan Honker military vehicle. M1 – module of the final drive and differential gear in the rear axle (with a diagnostic connection); M2 – module of the final drive and differential gear in the front axle (with a diagnostic connection); M3 – transfer case and reduction gear module (with a diagnostic connection); M4 – engine and gearbox module (with a diagnostic connection); M5 – status analysis and data visualization module; 11, 12 – motion sensor of rear axle wheels; 13 – motion sensor of the final drive (rear axle); 14 – temperature sensor of the final drive (rear axle); 15 – vibration sensor of the final drive (rear axle); 21, 22 – motion sensor of front axle wheels; 23 – motion sensor of the final drive (front axle); 24 – temperature sensor of the final drive (front axle); 25 – vibration sensor of the final drive (front axle); 31 – motion sensor at reduction gear output (front axle); 32 – motion sensor at reduction gear output (rear axle); 33 – reduction gear activation sensor; 34 – temperature sensor of reduction gear; 35 – vibration sensor of reduction gear; 41 – crankshaft speed sensor; 42 – fuel injection sensor; 43 – engine coolant temperature sensor; 44 – oil temperature sensor (measurement at the filter); 45 – engine lubricant level sensor; 46 – gearbox vibration sensor; 47 – gear shift position sensor; 48 – gearbox temperature sensor; 49 – fuel level sensor; 410 – engine coolant temperature sensor (measurement at the radiator); 411 – coolant level sensor; 412 – clutch position sensor; 413 –brake fluid level sensor; 414 – ambient temperature sensor; 51 – fault signal pilot lamp; 52 – fault acoustic signal speaker; 53 – GPS module

Receiver-type actuating modules (modules 1, 2, 3 and 4) were placed in aluminum boxes and mounted under the chassis. Receiver-transmitter module (No. 5) was placed in the driver's cab (Fig. 4). The modules were linked by a network of data transmission and feed buses. The modules were also connected to measuring sensors with multipin plugs and connectors. All measuring sensors were installed separately, and they did not constitute built-in vehicle equipment.

Every module has a diagnostic connection for entering data into processor memory and for module self-testing. A manual tester has been developed for self-diagnosing individual modules. System software and the ALS control panel have been designed to produce a clear and intuitive user interface. The main goal of the optimization process was to maximize the information content of displayed data. Efforts were made to reduce to the minimum the number of panel keys required to operate the system, and visual and audio signals were deployed.

Fig. 4. View of the control panel in the prototype of the ALS v1.0 system (module No. 5)

Owing to the vehicle's functional characteristics (all-terrain vehicle), an LCD touch screen was abandoned during preliminary tests. When the vehicle is driven in uneven terrain, screen buttons are difficult to control, and they are almost impossible to operate at low temperatures.

5. Conclusions

An analysis of the physical model of the Autonomic Logistics System (ALS) in the Tarpan Honker military vehicle leads to the following conclusions:

− diagnostic information obtained from the data transmission system was used to develop a diagnostic model, algorithms for identifying the status of various circuits, algorithms for monitoring and displaying operating parameters on the control panel of the diagnostic system;

− a physical model of an on-board diagnostic and monitoring system for the Tarpan Honker military vehicle was developed;

− the ALS system comprised transmission-receiver modules which form an RS-485 type communication and data transmission system. The modules were individually designed and provided with measuring sensors using multipin plugs and connectors. All measuring sensors were installed in the vehicle, and most of them were not part of built-in equipment;

− every module has a diagnostic connection for entering data into processor memory and for module self-testing. A manual tester has been developed for self-diagnosing individual modules;

− the algorithm developed for module No. 5 features mechanisms for diagnosing individual models, but a tester can be used to diagnose any module without the need to activate the entire system. This is a highly useful option for diagnosing sensor and connection socket damage;

− the main goal of the optimization process was to maximize the information content of displayed data. Efforts were made to reduce to the minimum the number of panel keys required to operate the system, and visual and audio signals were deployed;

− the implemented system is independent of the vehicle's internal circuits, therefore, if damaged or not activated, it does not affect the mission performance;

− the ALS system was tested by the Military Institute of Armor and Automotive Technology in Sulejówek, and the results of the inspection confirmed that it is a useful and functional system (with regard to ease of use, metrological traceability of actuating elements and diagnostic

algorithms) characterized by high durability (system elements are resistant to low temperatures, dust and mechanical vibration).

References

[1] Kościelny J. M., *Diagnostyka zautomatyzowanych procesów przemysłowych*, Akademicka Oficyna Wydawnicza EXIT, Warszawa 2001.
[2] Merkisz J., Mazurek S., *Pokładowe systemy diagnostyczne pojazdów samochodowych,* WKŁ, Warszawa 2002.
[3] Młokosiewicz J. R., *Metoda wielopoziomowego badania stanu obiektów technicznych i synteza systemu diagnostycznego*, Nr 1734/87, Wojskowa Akademia Techniczna, Warszawa 1987.
[4] Niziński S. i inni, *Systemy diagnostyczne wojskowych pojazdów mechanicznych*, ITE Radom 2011.
[5] Niziński S. Michalski R., *Diagnostyka obiektów technicznych*, Instytut Technologii Eksploatacji, Radom 2002.
[6] Niziński S. Rychlik A., *Hierarchiczny model diagnostyczny wojskowego pojazdu mechanicznego*, Biuletyn WAT, Vol. LX, Nr1,Warszawa 2011, s. 196÷209.
[7] Wołejszo J., Siedlicki M., *Walka sieciocentryczna wyzwaniem XXI wieku*, Zeszyty Naukowe AON, Nr 3/68/A, Warszawa 2007.