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THE USAGE OF BOARD COMPUTERS IN TRACTORS

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ВИКОРИСТАННЯ БОРТОВИХ КОМП'ЮТЕРІВ У ТРАКТОРАХ

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The work objective was identification of present state and trends of board computer usage in tractors available in Polish and European market. Automation of construction machines is widely used in land management to improve the accuracy of the marking works during geodetic control. Investigation have included: automatic control of unit monitoring – before and after starting up engine, electronic system of automatic, damage engine switching off; fuel dosage control (engine rotary speed), radar sensor, ventilation; gear box – gear change, gear programming, damage diagnosis; lever – electronic steering system, damage diagnosis, steering keys outside cab. To basic tractor units equipped with electronic steering belong: engine, gear box, lever, live axle, power take off, radar, air-conditioner, planning.

Keywords: *tractor, board computer, automatic control in tractors, optimization of parameters.*

У статті розглядається використання бортових комп'ютерів у тракторах. Автоматизація будівельних машин широко використовується в землевпорядкуванні, що підвищує точність виконання розмічувальних робіт при геодезичному контролі. Мета роботи полягала у визначенні сучасного стану і тенденцій використання бортового комп'ютера у тракторах, доступних на польському та європейському ринках. Проаналізовано трактори потужністю двигуна від 60 до 194 кВт компаній Case, Deutz, Fahr, Fendt, New Holland, John Deere, Massey Ferguson, Lamborghini, Valmet, Renault. Дослідження включали автоматичне управління моніторингом агрегату – до і після запуску двигуна, електронну систему автоматики, пошкодження вимикання двигуна; контроль дозування палива (частота обертання двигуна), радіолокаційний датчик, вентиляцію; коробку передач – зміна передач, програмування передач, діагностика пошкоджень; важіль – електронна система рульового управління, діагностика пошкоджень, рульові клавіші поза кабіною. До основних тракторних агрегатів, оснащених електронним рульовим управлінням, належать двигун (автоматичне управління – перевірка встановленого обладнання, контроль дозування палива), коробка передач (зміна, програмування, діагностика пошкоджень), важіль (управління, діагностика пошкоджень), жива вісь (блокування диференціального механізму, привод 4x4 вмикання/вимикання, система управління для блокування та привода 4x4, електронне управління підвіскою передньої осі), вимикання живлення (вмикання/вимикання, регулювання обороту, діагностика пошкоджень), радари

(вимірювання реальної швидкості руху), кондиціонер, планування (програмування функцій блока, робочих параметрів, надання консультацій). Інші системи, що знаходяться в стадії розроблення і які, як очікується, будуть впроваджені найближчим часом і можуть бути цікавими для польських користувачів з точки зору безпеки праці: сигнальний пристрій ризику балансування трактора, який може бути доданий до незалежного розділу до вимог користувача до трактора або є частиною бортової комп'ютерної системи та електронного блока, що контролює автоматичне кріплення (підвіску) інструментів.

Ключові слова: *трактор, бортовий комп'ютер, автоматичний контроль у тракторах, автоматизація параметрів.*

Introduction. Since 1989 in Polish market there have been offered modern tractors, produced by Western companies, equipped with electronic steering and control systems [1, 2]. These systems include microprocessors for particular tractor unit service or board computer (microprocessor, microcomputer) for steering and control of several tractor units. Today, with the wide use of mechanization of works geodetic control is combined with geodetic monitoring for work of executive devices of earthmoving machines at construction of formation. Geodetic monitoring is providing installation and moving executive devices of the construction machine in accordance with the specified design position. In Polish agriculture only small percentage of tractors is equipped with such systems.

According to the Institute of Technology and Life Sciences, Mazovian Research Centre in Kłudzienko forecast – in the coming years the sale of such tractors in Polish market will be growing, mainly because of the increase of economic and ecological requirements and work quality, comfort of driving and service [3]. It is forcing the technical progress improving tractor designs and adjusting them to new requirements. More and more effective control systems are introduced to improve agricultural tractor usage. Transmission of signals between them (communication) enables realization of complex agro technical operations with quality (precision, accuracy) impossible to be reached by traditional (mechanical) driving systems of tractors and agricultural machinery.

Introduction of numerical techniques, allowing transmission of large number of information with significantly reduced number of cables was especially important from the point of view of application of electronics in tractors.

Statistic in Figure 1 shows the share of tractor registrations in Poland in 2015 by brand, in percent. The american companies New Holland and John Deere took the two spots at the top of the table, while the Czech brand Zetor was the third largest seller of tractors, claiming 13.47 percent of the polish market [4].

Statistic shows the share of the European tractor market held by the largest tractor brands in 2015. American brand John Deere holds the greatest share of the market, followed by New Holland, Fendt and Massey Ferguson. These four brands combine for more than half the total sales of tractors in Europe. While John Deere was the single brand with the largest share of sales in Europe, although the Case New Holland group (which consists of New Holland, Case IH and Steyr) was the largest group in the market [5].

Computer control systems are going to take over more and more functions, not only in operating, but also in tractor diagnostics. The computer shall not only detect the failure but it shall inform the nearest authorized service to prepare all necessary parts for repair including term of repair the tractor. Further, it shall forecast tractor's failure and informs the operator-owner on time. All these tasks will be simplified by geographical positioning system (GPS) system, which locates the position of the tractor on-line. It is assumed that in the near future, tractor shall be operated by remote control from the control center [6].

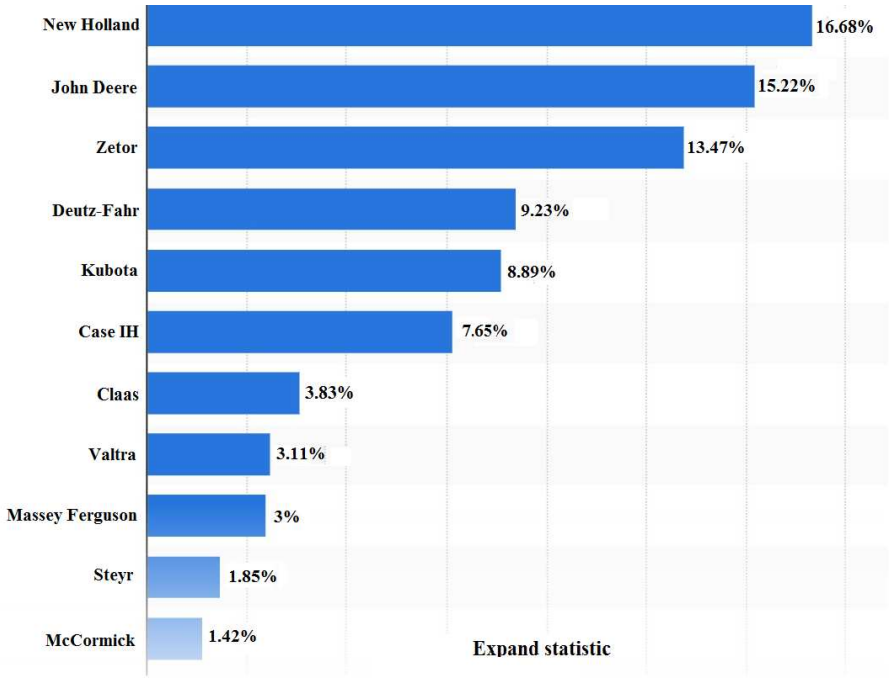

Fig. 1. Market share for brands of tractors in Poland 2015 [4]

Research objective. The objective of investigations was a trial of assessment of board computer usage possibility in tractors. The analysis was based on tractors produced by Case, Deutz, Fahr, Fendt, New Holland, John Deere, Massey Ferguson, Lamborghini, Valmet, Renault companies, sold in the largest quantities in the Polish market.

Analysis. In tractors the systems of engine, gearbox, hydraulic ram, rear-wheel steering etc. can be linked together by cables transmitting digital data [7]. Steering and control systems located in the machines aggregated with tractor can co-operate with board computer installed in tractor. Usage of electronic system controlling interactions of system including: driver, tractor, machine and soil gives huge possibilities of improvement of aggregate work results, among others by: efficiency increase, fuel consumption decrease. Electronic adjustment of machines requires the compatibility of tractor computer, machine processor, cables and couplings necessary for connection of computer with machine processor to be achieved. Those units have been already standardized, and that is why the tractor may be aggregated with machines equipped with electronic systems produced by different manufacturers. There are growing possibilities of electronic steering of farm tractor functions in two new technical solutions: system of tractor positioning in the field and system of mutual telecommunication between tractor, machine and office [8]. Recently Companies have demonstrated new tractors with hydrostatic drive and automating steering system without cabs and drivers, but in practice, those systems are not offered in Polish market.

The companies existing in Polish market equip their tractors with computer systems for measurement, registration, monitoring and automatic control of working parameters. In Poland there have been already distributed systems of indicators informing of a tractor malfunction and what is the remedy, as well as diagnostic systems applied in repair shops, simple electronic control devices (e.g. electronic limiter of rotation number, limiter of TUZ-[three point suspension system] upper position), microprocessor systems for several parameters control in particular sets of tractor (e.g. lift, gear box or engine), complex systems for automatic control of tractor-agricultural

machine aggregates with board computers usage with modular structure (with possibility of adding of modules and enlarging by that the range of control) together with steering elements (electric valves, sensors) installed in tractor units and interconnected by a signal transmission bus.

Electronic units in tractor. Electronic units in tractor include: tractor's units driving system (engine, gear box, lift, chassis etc.); information, regulation, control (process control, information about switched units, tractor drives, fixed working parameters, gear change, switching in and out of front shaft drive etc.); diagnostics allowing system self-control, analysis and signaling of damages and places of their appearance; management (collection of work results e.g. work time, cultivated area, harvested yield, consumed materials, costs, undertaking of decisions about changes of work regimes etc.); aggregate tractor-machine function connected among others with transmission of data from machine sensors to board computer at tractor and control of aggregate work parameters; satellite system of fixing the machine position on field (satellite navigation); telecommunication system between tractor board computer and stationary computer at the office.

Analysis of existing solutions has shown, that electronic steering systems should have modular structure with mains joining particular modules in one unit, forming integrated (not fully) automatic system of electronic aggregate steering with usage of board computer, as it has been applied e.g. in Lamborghini 165 Racing computer (see Fig. 2). At present the steering is done by comparison of values of different tractor working parameters (e.g. real wheel slippage value, adjustment driving force to optimal value and other parameters and their optimization), as the optimization criterion there is often used the efficiency maximization or fuel consumption minimization.

The main factor deciding of the working quality of automatic systems applied in farm machinery driving units is the quality of signal provided by a head unit [9]. Taking into account disturbances factors, maximal accuracy of machinery positioning is situated in the range from 3 to 5 meters. For improvement of accuracy positioning, correction signals are utilized. John Deere Company has its own StarFire correction network and makes accessible free of charge correction signal SF1, which makes possible to evaluate certain placement with accuracy of 30 centimeters. For signal SF2 with 10 centimeters accuracy of placement, customers have to pay for this service. But by providing private reference station RTK, it is possible to obtain 1 to 2 centimeters of accuracy. Receiver iTC makes it possible to receive all tree signals SF1, SF2 I RTK. Definition iTC means, that each standard John Deere receiver is equipped in "Terrain Compensation Module", which makes possible to work on slopes. There are three different guidance systems for driving agricultural machines in the field: Parallel tracking, Universal AutoTrac and AutoTrac. Paralel Tracking is the simplest system for machinery guiding in the field. System operation consists in determination of the first passage and then introduction of machine working width value. This system enables the field works to be done without markers, when visibility is poor and at night.

Universal AutoTrack is equipped with fully automatic machine driving. It consists of an antenna and a screen. Additional element contains a special steering mechanism installed in a steering column and a special card which activates automatic guiding of the machine. AutoTrac system is dedicated to the new farm machinery developed by John Deere and requires the installation of special modules to the hydraulic steering unit to provide parallel driving called AutoTrac Ready.

All systems described above are equipped with the same type of screen GS4, the same receiver StarFire iTC and they can recognize all offered correction signals SF1, SF2, SF3 and RTK. They differ only by the elements installed in a certain model of machinery and certain types of activated options. A selection of accuracy depending on different type of field work is characterized in table 1.

Fig. 2. Lamborghini 165 Racing tractor equipped with board computer (electronic control device): a – control panel shoving e.g. witch units are working, gear change, in/of front axis drive, differential mechanism locking, WOM (PTO), work parameters of engine gear box – oil pressure in engine, box, oil temperature, cooling fluid etc. and faults; b – multifunction steering lever – gear change, adjustment of engine rotary velocity, lifting link control; c – engine rotary velocity programmer; d – steering console for front and back WOM (PTO), in/of 4x4 drive, differential mechanism blocking, SBA system; e – lifting link steering panel – up/down, locking, transport, control of up/down speed, adjustment of work parameters (power, position, slippage), alarm, steering keys on wing; f – radar sensor of driving velocity; g – data monitor – shows e.g. tractor velocity, engine and WOM (PTO) rotary velocity, slippage, tool working depth, working width, cultivated area, work period, efficiency etc.; h – camera with monitor for machine watching from tractor back. Source: own elaboration

Table 1

Accuracy selection depending on different types of field work [10]

AutoTrac option	Optimal to:	Correction signal	Accuracy
AutoTracSF1	Tillage Fertilization Spraying	SF1 (free of charge)	+/-33cm +/-16,5cm +/-11cm
AutoTracSF2	Planting/sowing Spraying/fertilization Harvesting	SF2 (subscription)	+/-10cm +/-5cm +/-3,5cm
AutoTrac RTK	Planting Deep tillage Repeatable intertillage	RTK (single activation)	+/-2cm Repeatable

TPI Company offers parallel navigation system called TOPCO SYSTEM 110 which is dedicated to provide all agriculture field operations requiring parallel driving as it is shown in Fig. 3,a. Color screen enables field work to be done during a day and at night as

well. Consol system 110 with a screen allows selection of tree different ways of work: straight AB, two types of curves or movement along a circle. It is also possible to provide an automatic reversing. On a screen of console, we can find the following information: driving speed, area of cultivated field, number of passes, number of accessible satellites, deflection from the driving pass. System is equipped in 3 USB connectors type 12 pin DTM06-12S Deutsch and two types of GPS antennas: AGE-1 and AGE-2 with frequency measurement of 20 Hz.

a) b)

Fig. 3. Positioning system made by TPI Company [11]:
a – TOPCON System 110; b – TOPCON System 150

Recent solution developed by this company is a precision system of automatic steering called TOPCON System 150 of 2 centimeters accuracy – it is shown in Fig. 3,b. In this solution the newest technology of precise positioning of Japanese corporation TOPCON is applied.

At present the most popular systems applied in tractors available in Polish market are included in the first four groups mentioned above. They will be especially analyzed because of their widest usage. They directly concern the tractor, but not the external systems connected with electronic steering of agricultural machines, satellite navigation, co-operating computers installed in the office. Electronic linking of tractor units (assemblies) enables creation of work control system almost in an optimal way. To achieve this goal, the units should be arranged in the way enabling measurement of characteristic parameters to be done and they should be equipped with control devices as well. The very essential elements of electronic systems are indicators and instruments for measurement of functional parameters, being the input data for control systems. Quality of control and steering significantly depends on quality and reliability (stability) of sensors and gauges. In a lot of cases just only placement of sensors or gauges has caused particular technical problems, connected e.g. with space they are to be located, structural limitations of tractor's construction, tractor units, measuring instruments size and reliability (stability): technical quality and measurement precision (e.g. fuel consumption gauge, sensor on shafts working in oil etc.).

Engine electronic systems. Engines are equipped with electronic injection system to control and steer the engine work by proper fuel dosage that allows reduction of both – fuel consumption and harmful chemical compounds emission to the environment – to be achieved. It is automatically done, without any operator invention. Realization of such steering standard requires installation of about 20 sensors in the engine to measure its work (oil pressure in engine, gearbox, oil temperature, cooling liquid, etc.). Modern tractors are equipped with electronic acceleration systems with manual control. An operator adjusts the engine rotary speed by the use of switches buttons, and through the

control unit. Such an engine revolution adjustment allows you to save and switch on the minimal or maximal revolutions, temporal keeping of preset revolutions and to return, by pressing push-return button, to acceleration control by means of the accelerator pedal.

Additionally, tractors are equipped with electronic units with automatic adjustment of gearbox ratios according to tractor speed and wheel slip. Switching of gear is done by signal transmission (by key push) to microprocessor, which completes calculations and switches adequate pair of gear-wheels with hydraulic steering. Some tractors of SAME company are equipped with MULTISPEED gear boxes, where engine output power is controlled by electronic steering system, sending adequate data to the central unit. Depending on engine power the steering system sets up the proper work mode – SOFT (economical) or HARD (maximal possibilities). If steering system discovers errors (damaged coil of electronic control valve, locked key, lack of engine power) it signals them by code. Usage of gear box MULTISPEED (switches MULTISPEED) enables constant power flux transferred from engine to gear box and tractor wheels, allowing for efficiency increase, operation time shortening, and by the same – fuel and costs reduction. Selection of adequate mode of gear work, range, speed, drive direction is done by keys without pushing the accelerator (under load).

In case of automatic gears, steered by AUTOMATIC-POWER-SHIFT system e.g. in DEUTZ-FAHR company tractors (Agrotron 160, 175, 200) it is not only possible to select gear work mode ECO (economical) or POWER (maximum of possibilities), range of speeds (gear group), particular gear, drive direction but also to programme gear box in such way, that gear can be directly switched or can be reduced – e.g. gear in upper range of speeds above which system does not change the gear.

In Polish market a share of tractors with four-wheel drive is growing. In typical solution invariable position in front axle drive is used, and difference of wheel peripheral speed in relation to rear axle should range from 1 to 5 %. It causes tensions in driving unit between front and rear axle, reducing the transferred power. For reduction of power looses in driving unit the special electronic sensors are used allowing switching on or off by clutch of front axle hydraulic drive in the moment of tension appearance. In standard-equipped tractors an operator must often switch on and off gear drive and lock differential mechanism manually by lever as well as to lock differential mechanism. Usage of front axle drive and differential mechanism locking is necessary during work in bad adherence conditions, during field works, with high wheels turn, work on slopes, driving on damaged ground or road surface. For that reason, tractors are optionally equipped with front drive and electro-hydraulic interlocking of differential mechanism switched on by pressing the keys. However, an operator has still often had to connect and disconnect front drive and locks. To avoid the above inconvenience, the tractor may be equipped with electronic steering system e.g. SBA System Control in tractor of LAMBORGHINI (e.g. 165, 190 Racing), where automatic control of two functions appears simultaneously. Four-wheel drive is typically switched on during field works and automatically switched off when tractor speed equals 15 km/h. Differential mechanism is usually locked, lock is released when asymmetric braking up appears, speed exceeds 15 km/h, wheel turn exceeds 20o angle at speed lower than 10 km/h or turning has angle greater than 5o at speed exceeding 10 km/h. Given ranges of speeds and angles are connected with calculated hysteresis curve and when the next locking condition of differential mechanism occurs, locking appears when tractor speed is lower then 2 km/h or turn angle is smallest than 3o. Thanks to that tractor does not loose its controllability during work on heavy soils. When necessity of turning with angle exceeding 20o appears, then automatic unlocking of differential mechanism occurs and possibilities of tractor

handling are increased. When SBA system key is switched off, direct drive on four wheels and differential locking is manually started by electro-hydraulic lever and even the tractor is equipped with steering unit SBA, it does not meet any control function. When SBA is switched on, the system launches power to front axle and it locks differential mechanism according to tractor speed and turn the angle of front wheels irrespective of the position of the lever for electro-hydraulic unit steering. When SBA is switched off the locking and front drive mechanisms are switched on according to lever position, so one must be careful during e.g. system switching off with high speed, when lever is in position of front drive switching on.

In modern tractors lift is adjusted by electronic unit from steering panel. Electronic steering unit is standard version or it is included to the system together with electronic steering of acceleration (engine revolutions) and gear box. In this case the tractor is equipped with multi-functional steering lever. Lift switches are also included in the system which, in dependence of work mode, controls electro-hydraulic valves of lifting system on basis of information transmitted from sensor. System consist of: steering unit, steering panel, electro hydraulic valves, hydraulic pump, power and position indicators, radar or wheel circular speed indicators, keys for lifting/lowering on wing for steering outside cab. System allows for lift steering in aspect of power, position and slippage. Steering unit is working in different modes: locking, transport, stopping, steering of smooth acceleration, slowing down, lifting/lowering, alarm, testing (used only in repair workshops). Each of three functions (power, position, slippage) can be chosen as main or auxiliary one, or not chosen at all. Computer controls the work parameters according to the above selection. The system gives diagnosis of steering unit damages (memory error, programming, electric), sensors (damage, disconnection), cables (main damage, disconnection), electric valves coils (short-circuit, disconnection). It is easy to locate damage and eventually try to maintenance – when sensor is disconnected, steering valve, cables are wrong connected, there is a lack of power, cable is broken; in other cases, one should ask service for help.

Besides the above mentioned units' tractors are equipped with electronic steering units: PTO in/off, indicating its starting up, automatically disconnecting PTO when engine stops, switching over of revolutions between 540, 750, 100, 1400 in normal or economical mode (in dependence of what is available at tractor), informing on digital screen about PTO rotary speed calculated on electronic unit on basis of engine revolutions and indicating system damages. Companies also equip some of their tractor models with automatic damage engine switching off system. For example, in CASE tractors (7200 type) digital control system is checking oil pressure in engine, oil temperature in gear box, oil pressure in gear box as well as cooling fluid temperature. If one of the mentioned parameters is not proper, than digital control unit shuts electricity intake to electromagnetic valve at injection pump and fuel in flow to the engine is stopped. System has locking unit switching off electronic control as well as indicators and acoustic signals connected with engine state in aspect of mentioned parameters. Moreover, for measurement of real driving speed radar sensors are used, what allows on precision determination of percentage value of wheel slippage in any work conditions. Percentage value of slippage is presented graphically on digital display in form of bar chart. Keeping up of recommended slippage allows for improving work efficiency, precision of dosage of e.g. chemical means, seed sowing and by the same results in reduction of costs and environment protection.

As regards other electronic systems there are used systems for front axle spring stiffness control, electronic adjustment of cab air-conditioner or in lever – electronic control of the tool during transport automatically lifting/lowering mounted tool for tractor stabilization within driving on a road. Other

electronic control units automatically check the tractor units (sets, drives) work. The state of controlled units is illustrated by the control lights and bar charts. System is checking and displaying information about such parameters as: switched gear, driving speed, wheel slippage, engine rotary speed, PTO rotary speed, moto-hours number, service period, working width, efficiency per hour, cultivated surface, work time and others.

Among electronic systems of automatic steering used at present in tractors there are also system advising driver in selection of the best steering solution. Such systems are not only measuring and monitoring parameters of tractor work, but are also assessing parameter values, for which the best technical and economic indicators are reached according to chosen criteria and with tractor loading (engine, driving units). Next they are indicating to driver, which operation should be done for tractor changing over from present parameters to optimal ones. For that reason, electronic system is calculating criterion indicator value for sequence of tested parameters and calculates it optimal value according to the program. After that system is informing driver about calculation results in form adequate for direct usage. Driver is undertaking decision. Such decision aiding systems are offered among others by such Western companies as: Datatronic, Uni-Control, Spartronic or Hessel.

Solutions under development. Other systems being under development and expected to be implemented in near future and which can be interesting for Polish users in aspect of work safety are: signaling device of tractor balance risk (aggregate), which can be independent section added on user requirement to tractor or being a part of board computer system and electronic unit controlling automatic mounting (suspension) of tools. Linking of tools and machines with tractor is operation often done and quite dangerous. Although automatic linking makes this operation easier, but it requires precise tractor access to the machine or tool. Such access in case of limited area of tractor handling is difficult and time-consuming. These disadvantages are eliminated by electronic device, enabling measurement of the distance between tool and tractor and by calculation of tractor turn angle by board computer, necessary for proper access to the tool, allowing for the automatic mounting.

Further possibility is idea of computer design with step-less adjustment of drive of all wheels in which mechanical system is substituted by hydrostatic drive. Electronic adjustment controls the hydraulic unit utilized to drive moment division according to load on both tractor axles. In that way step-less change was reached between front and rear axles.

Next step will be implementation of step-less tractor speed adjustment with usage of hydrostatic driving (hydraulic), next by elimination of cab and operator receiving of fully automated tractor with remote starting up and control. But at present and in near future in Polish agriculture the most important will be tractors equipped with electronic systems.

Conclusions. On basis of above analysis units (sections) with electronic steering were chosen as having a possibility of wider use in tractors on Polish market at present and in near future as follows: 1 – engine (automatic control – installed equipment test, fuel dosage control); 2 – gear box (change, programming, damage diagnosis); 3 – lever (control, damage diagnosis); 4 – live axle (differential mechanism locking, in/off 4x4 drive, control system for locking + 4x4 drive, electronic control of front axle suspension); 5 – power take off (in/off, revolution adjustment, damage diagnosis); 6 – radar (measurement of real driving speed); 7 – planning (programming of unit functions, working parameters, advising).

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