Modular design of diesel-electric tracked tractor with high degree of automation

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Abstract. The prospective diesel-electric tracked tractor shall have a modular design, integrating the power frame, auxiliary systems, and control system. The tractor will have the following basic modules: a track module comprising an electric motor, gearbox, brake system, electric motor power casing; a diesel generator module consisting of an internal combustion engine of the power corresponding to the tractor's traction class and a power generator. The article substantiates the need for a diesel-electric tracked tractor with a high degree of automation and unmanned control capability, which will be in demand in modern Digital Agriculture. The stages of technological change in global agriculture are presented. The paper outlines the advantages of tracklaying system and electromechanical transmission; functional diagram and target indicators of some technical characteristics of a diesel-electric tracked tractor with the electromechanical transmission; capabilities and functions of information and control digital, intelligent systems that are to be implemented in a diesel-electric tracked tractor for digital agriculture production.

1. Introduction
Agriculture becomes increasingly important in the era of increasing globalization. First, sharp population growth and the associated increase in demand for food products set new challenges for agricultural producers. They are forced to ensure that they will continue producing enough food in the future while making a profit.

The solution to this problem is to use precision farming. To cultivate land and plants as accurately as possible, agricultural machinery shall be adapted to the corresponding soil characteristics.

To achieve these goals, all the world manufacturers of tractors (John Deere, Claas, CNH, etc.) as well as of trailed and mounted implements (Amazone, LEMKEN, KUHN, etc.) now equip their products with digital intelligent and control, information systems. These systems provide an opportunity to control the tractor-implement unit in the complex, which allows:

- convert agricultural production to advanced digital, intelligent production technologies;
- use systems of remote monitoring, control of technical condition and diagnostics of the tractor-implement unit;
- increase automation, productivity, and quality of works performed in the agricultural production;
- perform all work processes with maximum accuracy, which increases the volume of the crop and reduces the time, money, and efforts for its production;
- improve the economic performance of the tractor-implement unit (reduce costs for fuel, lubricants, and working fluids);
• reduce the level of professional requirements to the operator;
• ensure compliance with the requirements for safety and environmental protection.

In the Strategy for development of agricultural engineering industry of Russia through 2030, it is specified that the volume of agricultural machinery manufacture in monetary terms shall increase threefold up to about 300 billion rubles. The volume of investment in research and development shall increase to 10 billion rubles and exports of Russian products of the agricultural engineering industry shall reach about 100 billion rubles. The scope of this Strategy includes agricultural tractors (wheeled and tracked) among other agricultural machinery used in the production of main crop products, including forage crops [1]. The structure of the agricultural machinery market will remain stable in the future. Agricultural tractors shall occupy 27 percent of this market in 2030. The sales volume of agricultural tractors shall reach 46.7 billion rubles by 2021, 57.7 billion rubles by 2025, and 71.5 billion rubles by 2030.

About 6 thousand agricultural tractors were manufactured in the Russian Federation in 2019, in 1990, at the beginning of reforms, 213.6 thousand machines were manufactured. During these years, the production of agricultural tractors decreased by more than 30 times. Since the late 1990s, the Russian Federation has produced as many tractors as in the first postwar years in the RSFSR. In this regard, the fleet of agricultural tractors in Russia is characterized by a critically insufficient size and a high degree of wear. The share of Russian manufacturers in the segment of agricultural tractors with 100-200 hp engines (middle class), including those assembling of semi-knocked-down kits, does not exceed 10 percent.

Preservation and improvement of soil fertility is the main task of agricultural production in the long term, as it determines the competitiveness and profitability of agricultural sectors. In this regard, there is a growing demand for resource-saving machinery and equipment, which provide a minimal negative impact on the soil, including the wider use of agricultural tracked tractors.

Because of the above, there is an urgent need in Russia to produce a middle-class agricultural tractor for “Digital Agriculture” being created using the latest achievements of scientific and technological progress in its design.

2. Purpose of work
To reveal the demand for the development of a high-tech tracked tractor equipped with modern control and information systems to be used in the modern “Digital Agriculture” that is being created.

3. Problem setting
To demonstrate the demand for the development of a high-tech tracked tractor with a high degree of automation, based on the analysis of trends in the development of technological paradigms in the global agriculture, taking place in the world.

4. Results
Agriculture in developed countries has already gone through several stages of technology change. In the early 2000s, the current stage of the “Digital Age” began (Figure 1). At this stage of technology development, a “smart” tractor is required, which will be seamlessly integrated into the new “Digital Agriculture” [2].
Currently, the first stage of the formation of the system of digital control of agricultural sector is underway (Figure 2).

Reducing the impact of compaction effect of agricultural machinery wheels on the soil is possible in three directions:

1) technological, which consists in improving the technology of crop cultivation, including reducing the number of passes (especially in unfavorable soil conditions), and implies: choice of rational routes of implement movement, application of combined and wide-capacity implements, minimum soil tillage, use of constant technological track and bridge system of arable farming, use of transloading technology for implement-tractor interaction, restriction of the use of heavy wheeled tractors on wet soil;

2) agronomic, which consists in improving the soil’s ability to withstand compaction and shear loads due to the application of a large number of organic fertilizers and limiting the use of chemical plant protection agents, performing fieldwork in the best agro-technical terms as well as the qualitative performance of tillage operations, including the additional loosening of the soil behind the wheels of tractors in case of its excessive compaction and loosening of subsoil layers;

3) constructive, which includes improving tractors, agricultural machinery, and their propellers, reducing the operating weight of tractors and agricultural machinery, the use of additional wheels or axles, trailers, as well as soil tillage machines with driven working units (cutters, rotary needle looseners, etc.).

One of the most rational ways to reduce the harmful impact on soil is to use tracked tractors instead of wheeled ones, especially on wet and loose soil during cultivation, harrowing, and sowing. However,
the known disadvantages of tracked tractors (quietness, high metal intensity, less versatility and durability, side shear of the soil when turning or turning around, inappropriate for use on paved roads) led to the fact that their share is reduced on the global market. Tractors produced by a number of foreign companies with elastic rubber tracks or rubber reinforced tracks (for example, the US Challenger tractor) have produced encouraging results on compaction of the soil. The average specific pressure has decreased to 45 kPa. Taking into account a great variety of climatic zones of Russia, the use of reinforced rubber tracks for a diesel-electric tractor is reasonable and caused by a number of advantages [3, 4]:

- Reduction of the compaction effect of the propulsion system on the soil, which will preserve its mechanical composition and fertility;
- The possibility of the early spring and late autumn start of the field works;
- Operation of machinery in conditions of high soil humidity;
- No damage to asphalt roads;
- Off-road capabilities comparable to traditional tracked platforms;
- Transport speed up to 40 km/h;
- Reduced external noise and improved working conditions in the operator’s cabin;
- Increase of traction efficiency due to less slipping of tracks.

The functional scheme of the diesel-electric tracked tractor being developed will include an internal combustion engine (ICE) – diesel, power generator, traction electric motors, final drives, energy storage. Creation and production of such tractors with electromechanical transmission will allow getting the following positive points [5]:

- The optimal traction performance is achieved by regulating and stabilizing the torque and speed in automatic mode. Keeping the torque within a wide speed range and shutting down the cylinders at low loads;
- The engine runs at all loads and speeds in optimum mode, which increases its life and reduces harmful emissions into the atmosphere;
- Independence of the power plant location. The absence of a strict kinematic connection between units allows the creation of different layout schemes. The free layout of the driven units gives good weight distribution and optimizes the soil loads;
- Higher durability of the tractor with traction electric motors compared to mechanical transmissions and maintainability due to the modular construction of the transmission;
- Possibility to use the tractor as a mobile power station in places with power supply interruptions;
- Increasing the versatility of the tractor through the use of electric track drive, which will allow adjusting the track width and agricultural clearance;
- Reduction of transmission operation costs due to reduction of consumables and increased maintenance intervals;
- Higher adaptability for remote control and robotics.

The structural possibility to dock two diesel-electric tracked tractors with an articulated joint into a tractor of a larger traction class will expand its application and increase the annual workload in terms of time. To implement this principle, the cabin shall be quickly removable. The tractor will be equipped with digital intelligent systems that will provide:

- Path management (driving) of the tractor-implement unit;
- Monitoring of operating parameters and condition of the tractor-implement unit;
- Monitoring of execution of technological operations;
- Monitoring of fields;
- Transfer of telemetric data;
- Development of logistic solutions for the tractor-implement unit and other objects related to it;
- Interaction with other objects related to the tractor-implement unit in automatic mode;
- Creation and accumulation of a database with information;
- Preservation of operator’s behavioral algorithms.
The nearest future is the Internet of Things (IoT) - a system of integrated computer networks and connected physical objects (things) with built-in sensors and software for data collection and exchange, with the ability to remotely monitor and control in automated mode, without human involvement. Trends in the development of agro-technologies and agricultural machinery in developed countries are:

- Integrated digital agro-technology in the system of “Internet of Things”;
- Automation and robotization of technological processes;
- Integrated digitalization of agricultural technologies, a unified management standard based on ISOBUS technology;
- Tractor-robot, unmanned ground vehicle with telemetric control;
- Use of alternative energy sources for motion;
- Autonomous mobile units controlled by “artificial intellect”.

In this connection, in the future the created diesel-electric tracked tractor may be adapted for operation in unmanned mode [6, 7]. For this purpose, it shall be equipped with special equipment and devices (figure 3).

**Figure 3.** Components for operating the diesel-electric tracked tractor in unmanned mode.

Table 1 shows some technical characteristics of a middle class tracked tractor, according to which the share of Russian manufacturers in the segment of agricultural tractors with 100-200 hp engines, considering the assembly of semi-knocked-down kits, does not exceed 10 percent. The values shown in the table can be corrected during the development of the tractor design.
Table 1. Target indicators for the development of the diesel-electric tracked tractor.

**GENERAL TECHNICAL SPECIFICATIONS**

| Parameter name                                         | Value                                      |
|--------------------------------------------------------|--------------------------------------------|
| Traction class                                         | 2                                          |
| Speed, km/h                                            | 0,3 - 40                                   |
| Engine model, type, ecological class                   | ZMZ-51432.10, diesel, Euro-4               |
| Rated engine power, kW (HP)                            | 84 (114)                                   |
| Transmission type                                      | Electromechanical                          |
| Power unit type                                        | Diesel generator                           |
| Track width, mm                                        | 1350 - 2150                                |
| Propulsion type                                        | Reinforced rubber tracks                   |
| Base/narrow track width, mm                            | 390 / 240                                  |
| Soil pressure, kgf/cm²                                  | 0,45                                       |
| Dimensions, L / W / H (without linkage system), mm     | 3300 / 1650 / 2970                         |
| Agrotechnical clearance, mm                           | 460 - 700                                  |
| Types of attachable agricultural implements            | Existing types and perspective samples of  |
|                                                        | domestic and foreign agricultural and      |
|                                                        | meliorative equipment for tractors of traction |
|                                                        | class 2                                    |
| Linkage system, location                               | Front, rear, side                          |
| Load capacity of the front/rear linkage, kg, at least   | 3300 / 4550                                |

**ELECTRIC SYSTEM**

| Type of power generator                                | Synchronous                               |
| Voltage output, V                                      | 400                                       |
| Current type                                           | Constant                                  |
| Type of electric motors of transmission, PTO shafts    | Valve-inductor                            |
| Transmission electric motors, quantity, power, kW      | 2 [38 or 4 [19]                          |
| Type of electric motor cooling system                  | Liquid                                    |
| PTO Location                                           | Rear / front / side                       |
| PTO Speed, min-1                                       | 540, 750, 1000                           |
| PTO drive power, options, kW                           | 38, 57, 87                               |
| Electric power storage, type                           | Battery, Li-on                            |
| Energy storage, capacity / voltage, Ah / V             | 16 / 320                                  |

5. Conclusion

Development and production of the diesel-electric tractor with reinforced rubber tracks of traction class 2, equipped with information and control digital, intelligent systems will promote:

- Advanced development of domestic tractor construction and production of components [8];
- Creation on the basis of this of tracked tractors of different traction classes;
- Conversion of tractors to environmentally friendly electric energy;
- Creation of new highly qualified workplaces;
- Increase the export potential of the Russian agricultural engineering industry;
- Increase the efficiency and productivity of agricultural production and ensure the digital transformation of agriculture through the introduction of advanced digital, intelligent technologies.
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