# MULTILEVEL CONTROL OF A TRANSPORT ROBOT

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**DOI: 10.17973/MMSJ.2022_06_2022089**

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The control systems of modern robots are multilevel. The upper level control of the transport robot by voice commands and simulation of its motion in the software product Microsoft Robotics Developer Studio are considered. Visual Programming Language for creating and debugging applications was used to simulate the motion of the transport robot. An Android tablet or mobile phone with an application is used to recognize voice commands and the robot can be controlled using the Bluetooth interface. A program has been developed that will allow a human to control the robot using speech. An example of simulation of the robot and its motion path using voice control is given. The developed control system allows the transport robot to follow from one target point to another using voice control. At a low level, optimal asynchronous motor based actuator control using a model oriented approach in SimInTech is considered.

**KEYWORDS**

voice commands, robot, actuator control, motor, simulation

## 1. INTRODUCTION

The use of transport robots (TR) can now automate the task of transporting heavy loads (workpieces, parts, tools) indoors, including in production halls. A transport robot can also be used as a platform for wheelchairs. Transport robots are planned for widespread use in unmanned production as part of the Industry 4.0 revolution. The transport robot is most conveniently controlled by voice commands, with reduced operator fatigue and increased speed and flexibility of command transmissions. Examples of intelligent control systems and transport robots are given in the literature [Kim 2018; Nikitin 2017].

Robots for agriculture have been gaining popularity in recent years, experts say. They attribute the increased interest in this field to the increasing level of technology availability, the expansion of robotic applications, and technological breakthroughs in the development of unmanned technologies. "As the price of a robotic solution gets lower, more and more companies are using robots to automate processes. In recent years, solutions for agriculture (plowing, seeding, monitoring), livestock production (milking, cleaning facilities), and horticulture (fruit picking, fertilizing, soil sampling) have been developed and proven effective. Autonomous tractors and combines from manufacturers all over the world (Russia, USA, Netherlands, India, Japan) appeared on the market," the authors of the research note.

According to their data, the global market of robots for agriculture grew by 30% in 2018 compared with the level of last year. "The market volume was $2.4 million. In 2019, the global agricultural robot market doubled from 2018 levels. Market growth in 2020-2022 is estimated at 50% annually," the analysts add. Farming is a labor-intensive job, but it is gradually becoming an automated process. It owes this feat to robots. In this section, we discuss how robots have impacted global agriculture. The global agricultural robotics market could grow to $20.6 billion in 2025.

According to the facts about robots in agriculture , this figure is set at $7.4 billion in 2020 and is projected to grow at an average annual growth rate of 22.8% through 2025. The main driving factor is the growing demand for automation of repetitive processes and the growing shortage. of human labor on farms.

Robots can effectively perform repetitive processes such as weed control, harvesting, picking, sorting, packing, seeding, spraying, thinning and pruning without human intervention. The market for agricultural drones will reach $6.2 billion in 2024.

Unmanned robots or UAVs (unmanned aerial vehicles) have one of the largest shares of the agricultural robotics market worldwide. This is due in part to their more frequent recent use and inexpensive methods of conducting field analysis of livestock farms with small to medium-sized industrial farms. In 2018, the market value of agricultural drones was $1.5 billion , with a projected average annual growth rate of 25.0% from 2019 to 2024.

The book [Gacovski 2021] discusses design activity on both software and hardware, application of PLC, and development of mechatronic systems in agricultural irrigation device. The book [Karkee 2021] writes about next concepts. Agricultural machinery technology needs to adapt to the demands for increased food production to support a growing world population. While at the same time, more volatile climatic and pandemic conditions make it necessary for machinery to accomplish agricultural field operations more quickly and efficiently. Emerging technologies are rapidly advancing, enabling greater autonomy and control of field operations. Because of the importance of agricultural machines in perceiving cropping conditions and implementing management decisions, they will be a key part of any smart, digital agriculture scheme. Additionally, agricultural and field robots will likely be a part of the agricultural machine portfolio of the future, because autonomous machines enable a step change in the degree of perception and control that can be accomplished when human operator limitations are a constraint. Nevertheless, this type of autonomy in agricultural robotics can only be achieved through the use of multiple layers of technology. As a foundational technology layer, agricultural robotics must have machine architecture with both hardware and software components required for the robot's function. Then the robot must be aware of its location and the environment and cropping system around it.

In the book [Karkee 2021] the dynamic models of transport robots in the MatLab Simulink program are considered. In the book [Pradeep 2020] describes modern control methods on artificial intelligence, automatic and robotic systems.

The article [Turygin 2021] is devoted to the issue of the day to develop mathematical models of control systems for UAVs, which in modern conditions are increasingly used in the agricultural industry [Bozek 2016]. This article discusses the development of a mathematical model for controlling UAV drives. The analysis of four main channels of UAV control is carried out: bank control, pitch control, yaw control and throttle control. The obtained differential equation was linearized by expanding into a Taylor series and cutting off all terms above the first order. As a result, expressions were obtained for the linearized propeller speed coefficient, the linearized input voltage coefficient, and the linearized constant coefficient. These three parameters can be used to describe the dynamics of all UAV direct current (DC) motors. A modified proportional integral differential (PID) controller has been proposed and structural control schemes have been developed for all four channels.

The article [Qazizada 2016] explain analysis of inertial navigation system and accelerometric, gyroscopic sensors and describe possibilities of their application for inertial navigation of mobile robot.

The aim of the paper is to develop control systems for transport robots operating in non-deterministic conditions based on fuzzy logic and voice control and optimal control of asynchronous motor based drives using a model-based approach in SimInTech at the bottom level.

## 2. MATERIAL AND METHODS

The sentence structure, phrase values and speech morphology have to be programmed, in particular in the form of "rules" for the robot, and then transmitted via Bluetooth.

An Android tablet or mobile phone with an app that can be used to recognise voice commands is used to control the robot using the Bluetooth interface. In addition to voice control, the app allows the robot to be controlled using buttons or the phone's built-in accelerometer. For example, a slider allows you to control the speed of the robot. Two buttons are used to turn on the front and rear lights of the robot. Indications include a flashing light when the phone is connected to the robot and arrows that show the direction the robot is moving.

Motion simulations of a voice-controlled transport robot were performed in the Microsoft Robotics Developer Studio software environment using the Visual Programming Language (VPL). VPL is a visual programming environment for creating and debugging applications.

The Microsoft Robotics Developer Studio visual programming language is used to build and debug software applications for robots, allows 3D simulation of the robot's movement in virtual space, using NVIDIA PhysX technology, which allows using a modern physical model, as well as this language has simplified access to sensors and actuators in the robot, and supports several languages, including C#, Visual Basic, .NET, JScript, and IronPython. But this VPL language also has a significant drawback: there is no consideration and support for the real operating environment, only its simulation is used to control the transport robot, which may not fully match the real prototype. The more accurate the model, the more adjustments it requires in the software.

A multi-level control system has an upper level and a lower level of control. The upper control level is the intelligent control level. The lower level is the executive level. The wheel speed on the lower level is controlled by a microcontroller which generates pulse width modulation (PWM) output signals. The two wheels are controlled independently of each other.

A program was developed that would allow a human to control the robot using speech. Speech recognition was set up using the Windows control panel. The robot performs the following voice commands: "Drive Forwards" - set the DrivePower variable in both wheels to 0.1; "End Drive" - set the DrivePower variable in both wheels to 0.0; "Turn Left" - Turn the robot to the left by 45 degrees (using the RotateDegrees call); "Turn Right" - Turns the robot to the right by 45 degrees; "Turn Around" rotates the robot 180 degrees.

Three additional commands were used: "Begin Learning" - In the learning state, the robot writes commands; "End Learning" - the command instructs the robot to stop recording commands; "Perform Actions" - if the robot has received a task (and learning has ended), it must respond to this command by performing the actions described in the task.

A speech recognition service has been added for receiving a verbal command. A speech recognizer from Servicestoolbox has been selected. The speech recognizer service uses grammars that define words and phrases. The speech recognizer Guiservice was used to set up the grammar. After training the robot, it executes voice commands in a virtual space in the VPL Microsoft Robotics Developer Studio software environment.

Let's consider structural scheme of TR control system. The operator panel is a mobile automated workstation and is designed to implement the functions of the upper level of TR control:

1) man-machine interface in the form of a virtual control panel on a mobile device (cellular phone, tablet, laptop) with voice control,

2) TV signal display on a mobile device.

Functions of intellectual controller or second level of control are fulfilled by ADAM-5510M programmable controller. These functions are: reception of commands sent by upper level, their processing and transmission to controllers of lower level; acquisition of data from controllers of lower level as well as from sensors, attached directly to the intellectual controller; processing of received data, their representation for transmission to upper level of control; control of state of subsystems of vehicle-towing; transmission to upper level of necessary information by its request: data received from controllers of lower level and attached sensors, state of subsystems of vehicle-towing, etc. ADAM-5510M controller has 4 slots for installation of expansion modules, runs on the built-in operating system ROM-DOS, has four COM-ports: COM1 (RS-232); COM2 (RS-485); COM3 (RS-232) is a programming port used only for writing application software to flash memory and for operating the controller from an external host computer while debugging programs with a special utility; COM4 can be set as either RS-232 or RS-485. A total of 960 kbytes of flash memory is available for storing application software files, including executable modules. When the controller is powered up, an executable whose name is written in the *autorun.bat* file is automatically started, thus ensuring that the required application program is started.

The ADAM4520I RS-232 to RS-485 converter on the RS-232 input side is connected in parallel to the controller's COM1 port. This port is used for communication with the upper control level. COM2 port is used for communication with the lower control level - drive controllers.

The lower level of control uses vector control for induction motors [Crowder 2020; El-Sharkawi 2019]. Vector control was originally developed for high performance motors that need to operate smoothly over the entire speed range, generate full torque at zero speed and have high dynamic characteristics, including fast acceleration and deceleration [Hughes 2019; Kim Sang-Hoon 2017; Saga 2020]. Vector control is becoming increasingly popular, across all industries, as induction motors have a number of advantages over DC motors [Nikitin 2020; Bozek 2018). It is expected that with the increasing computing power of microprocessors, vector control will eventually replace scalar control almost everywhere [Abramov 2018; Kuric 2021; Peterka 2020].

With vector control, an asynchronous or synchronous AC motor is controlled under all operating conditions, just like an independently excited DC motor. An AC motor behaves like a DC motor in which the magnetic field coupling and the armature flux ratio generated by the respective field current and armature (or torque component) are orthogonal, so that in torque control the field does not affect the flux ratio, hence the dynamic torque response is ensured [Bozek 2021; Shaytor 2020; Lekomtsev 2021; Saga 2014].

Vector control accordingly generates a three-phase PWM motor output voltage derived from a complex voltage vector to control a complex current vector derived from the input three-phase motor stator current through projections or back and forth rotations between the three-phase speed-dependent and time-dependent system. and a two-coordinate time-dependent rotating reference system for these vectors [Shaitor 2021; Jancarik 2019].

Such a complex spatial stator current vector can be defined in the (d, q) coordinate system with orthogonal components in the d (straight) and q (quadrature) axes, so that the magnetic coupling component of the current field is aligned with the d axis and the torque component of the current is aligned with the q axis [Hartansky 2017; Hartansky 2020]. The coordinate system (d, q) of the induction motor can be superimposed on the three-phase sinusoidal system of the instantaneous (a, b, c) motor as shown in the accompanying illustration (phases b and c are not shown for clarity). The system current vector components (d, q) allow conventional control, such as proportional and integral or PI control, as in the case of a DC motor [Kabzinski 2017; Boldea 2020]. There are two methods of vector control: direct field oriented control (DFOC) and indirect field oriented control (IFOC) or forward control, with indirect control being used more frequently because in closed loop mode such drives operate more easily over the entire speed range from zero speed to high speed [Hughes 2019; Kim Sang-Hoon 2017]. In feedback vector control, magnitude and angle feedback signals are calculated directly using so-called voltage or current models. In direct feedback control, the flux space angle and flux magnitude signals first measure the stator currents and rotor speed and then obtain the eigen-angle of the flux space by summing the rotor angle corresponding to the rotor speed and the calculated reference value of the slip angle corresponding to the slip frequency [Luo 2019].

Sensorless alternating current (AC) motor control is attractive in terms of cost and reliability. Sensorless control requires obtaining rotor speed information from measured stator voltages and currents in combination with open loop estimates or closed loop observers [Azzoug 2021].

Let us perform parametric synthesis of the PID control law based on a continuous motion module model. Let us define the following data and numerical values required for the synthesis of PID control law [Jain 2020; Turygin 2021]:

- optimization parameters (optimizable parameters) – coefficients of PID control law $K_P$, $K_I$, $K_D$;
- optimization criteria with step input action $U_0$ at 0.5% "tube" and $M_E$=$M_L$, we can assume the following;
- transient process should be without overshooting
- adjustable value $\omega_r$=5.66±0.28 rad.s$^{-1}$ (at 5% "tube"), $\omega_{r\_max}$=5.94 rad.s$^{-1}$, $\omega_{r\_min}$=5.38 rad.s$^{-1}$;
- the transient time $t_{pp}$ = 0.9 s, determined by the fact that the controlled variable $\omega_r$ enters the 5% "tube" area.

Such conditions should ensure that the control system moves from $\omega_r$=0 at $t$=0 to $\omega_r$=5.66±0.28 rad.s$^{-1}$ at $t$ = $t_{pp}$ = 0.9 s;

The model in SimInTech program for parametric synthesis of a continuous PID control law for induction motor (IM) with stand-alone voltage inverter (VI) is shown in Fig. 1. The schematic window with the opened block "Calculation of transition process time" is shown in Fig. 2.

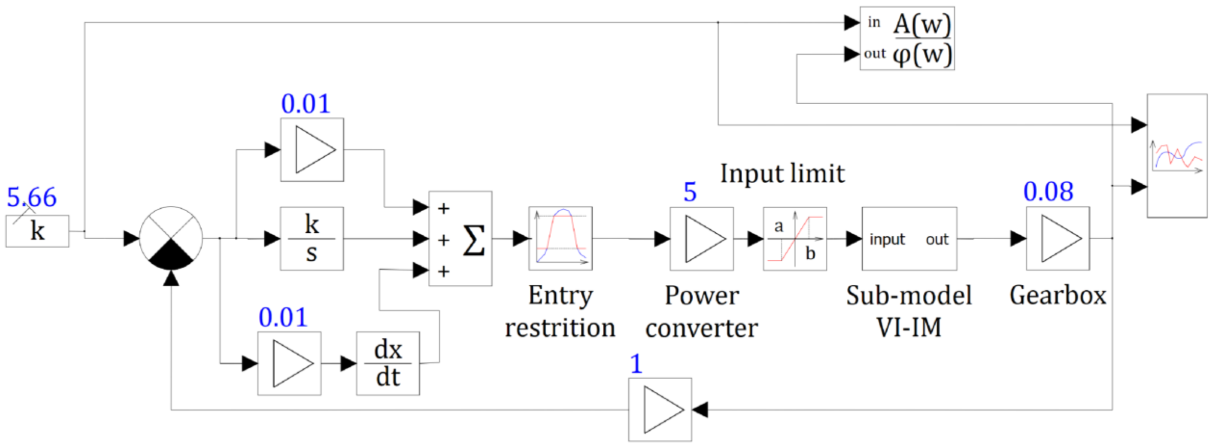


**Figure 1.** Model for parametric synthesis of a continuous PID control law

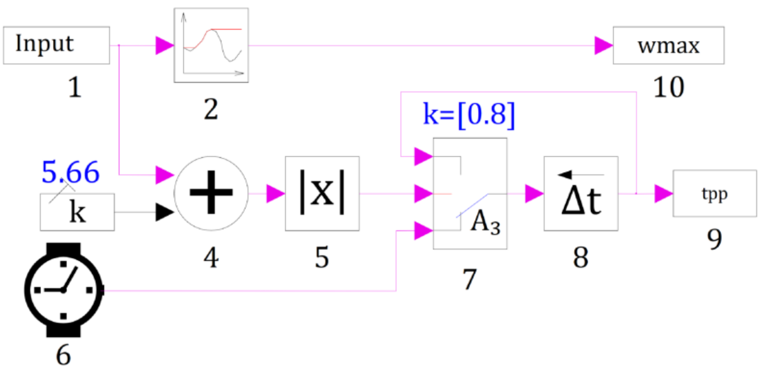


**Figure 2.** Expanded transition process time calculation sub-model

As an example, the calculation for uniform ascent uphill with 6% gradient of an empty TR weighing 1,700 kg, with a rated speed of 12 km.h$^{-1}$ is given. The results with optimised transient plots are shown in Fig. 3 for wheel angular velocity.

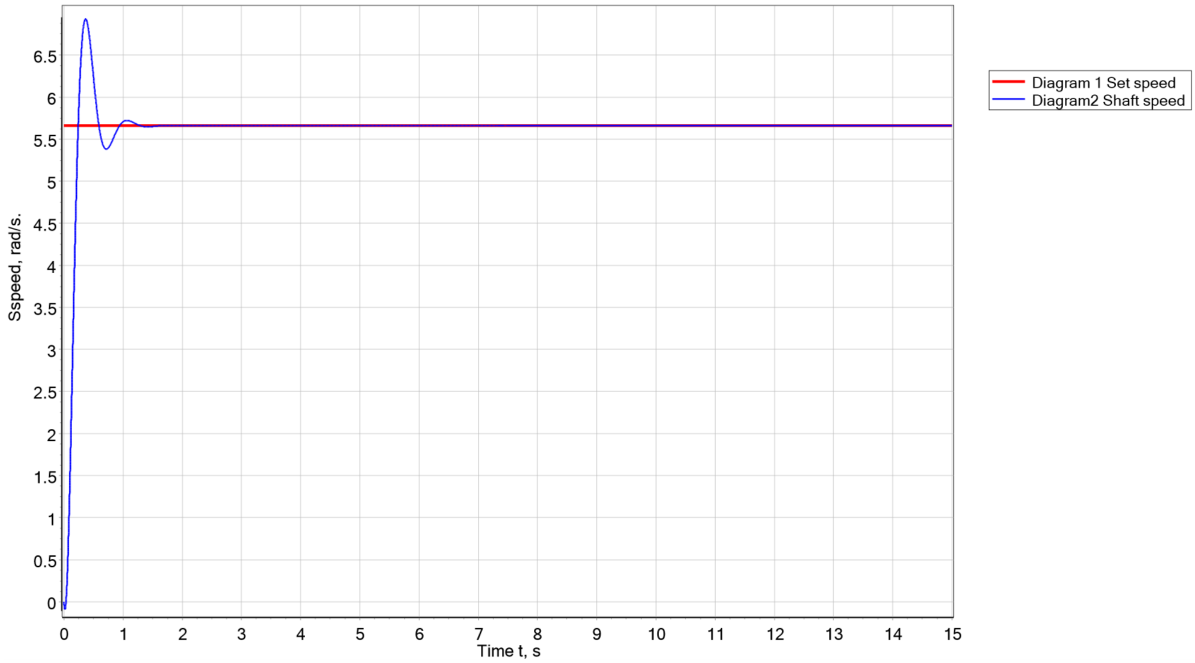


**Figure 3**. Graphical window of the Timeline block with optimised transient graph

Thus, as a result of parametric optimization of the PID control law based on a continuous model of a frequency-controlled drive the optimum values of its amplification factors are found: $K_p$=6; $K_i$=2.68; $K_d$=0.01, at which the transient time is $t_{pp}$ = 0.57 s, which is less than its prescribed allowable value of 0.9 s.

The control system uses sensors to determine the mass of the load and the inclination of the travel plane and automatically selects the optimum PID coefficients for the traction drive from a database (from empty to maximum load, 3 gradations (0, $m_{max/2}$, $m_{max}$), plane motion, uphill motion with 6% and 12% gradient (9 combinations in total). The optimum PID coefficients are then selected from the base. The required motor torque is calculated. The calculation is based on formulas (1-10). The input data for calculating the forces in the TR are shown in Tab. 1.

| | |
|---|---|
| Weight of the TR | $m = 1{,}700$ kg |
| Cargo weight | $m_\mathrm{r} = 2{,}000$ kg |
| Speed | $V = 12\dfrac{\mathrm{km}}{\mathrm{h}} = 3.333\dfrac{\mathrm{m}}{\mathrm{s}}$ |
| Wheel diameter | $D = 588$ mm |
| Efficiency of the gearbox | $\eta_{fr} = 0.95$ |
| Gear ratio | $i_r = 12.7$ |
| TR height | *B*=0.7 *m* |
| TR width | *H*=1.3 *m* |

**Table 1**. Input data for calculation of forces in TR

## 3. RESULTS AND DISCUSSION

In the calculations, the slope was converted from percentages to degrees and then to radians. The mass of the load was added to the mass of the TR. The results of the calculations of the required motor torques are shown in Tab. 2.

| Inclination of the plane, % | Weight of cargo, kg | | |
|---|---|---|---|
| | 0 | 1,000 | 2,000 |
| 0 | 8.38 | 13.16 | 17.94 |
| 6 | 33.18 | 52.54 | 71.91 |
| 12 | 57.85 | 91.73 | 125.6 |

**Table 2.** Results of calculations of the required motor torques, N·m

Finding the optimal coefficients of the PID controller. For each moment of resistance, the optimum PID coefficients are found and recorded in the Table 3. Table 3 shows PID regulator coefficients ($K_p$; $K_i$; $K_d$ for 9 combinations of weight of cargo (0; 1,000 kg; 2,000 kg) and inclination of

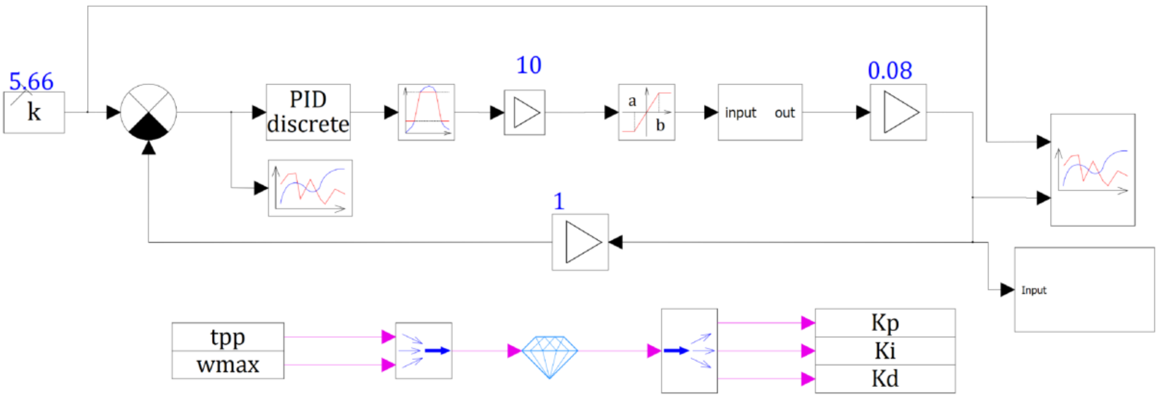


**Figure 4.** Model for parametric synthesis of a discrete PID control law with optimization results

the plane (0.6%, 12%). Fig. 4 shows model for parametric synthesis of a continuous PID control law with optimization results.

| | Weight of cargo, kg | | |
|---|---|---|---|
| Inclination of the plane, % | 0 | 1,000 | 2,000 |
| 0 | 5.84; 2.06; 0.01 | 6.42; 2.47; 0.01 | 5.9; 1.28; 0.31 |
| 6 | 6; 2.68; 0.01 | 6.62; 1.89; 0.01 | 6.78; 2.68; 0, |
| 12 | 5.33; 2.12; 0.02 | 6.63; 1.89; 0.01 | 7.15; 1.95; 0.39 |

**Table 3.** Found PID regulator coefficients for 9 combinations

After completion of the amplitude-frequency response calculation process, the boundary (maximum) value of the quantization period $T_{MAX}$ is calculated, at which the adequacy of the continuous model to its continuous-discrete motion module must be preserved:

$$T_{MAX} = \pi/\omega_{nMAX} = 3.14/167 = 0.0188 \text{ s} \approx 0.02 \text{ s}. \quad (1)$$

## 4. CONCLUSION

The developed control system allows a transport robot to follow from one target point to another using voice control. The task of controlling a robot using voice control is greatly simplified, since it requires almost no special skills from the operator. Ultimately, voice control will facilitate the use of robots in industry, household and other areas. It will be possible to control not only robots, but also other devices that have microprocessor control. When controlling multiple objects, the address of the object that will execute the command must be set, also using voice control.

Calculated torques on the TR motor shaft 8.38 N·m for driving without load at the rated speed, 18.14 N·m for driving with a load of 2,000 kg, 57.85 N·m for driving with a load of 2,000 kg at the rated speed, 125.61 N·m for driving at the rated speed.

Necessary torque at engine shaft at acceleration along horizontal surface of empty TR and with a load of 2,000 kg is 36.3 N·m and 61.15 N·m respectively. At acceleration up to 12% of TP with an empty load and with a load of 2,000 kg 85.83 N·m and 176.94 N·m respectively.

Induction motor has a maximum torque of 195 N·m at least, from which you can conclude that the selected asynchronous motor ADT6.0MP satisfies the traction requirements.

As a result of parametric optimization of the PID control law based on a continuous model of a frequency-controlled drive, the optimal values of its amplification coefficients are found: $K_p$ = 0.01; $K_i$ = 8.91; $K_d$ = 0.01, at which the transient time is $t_{tp}$ = 0.341 s, which is less than its specified permissible value 0.9 s.

## ACKNOWLEDGMENTS

This publication is the result of the project implementation: Comprehensive research of mitigation and adaptation measures to diminish the negative impacts of climate changes on forest ecosystems in Slovakia (FORRES), ITMS: 313011T678 (100 %) supported by the Operational Programme Integrated Infrastructure (OPII) funded by the ERDF.

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