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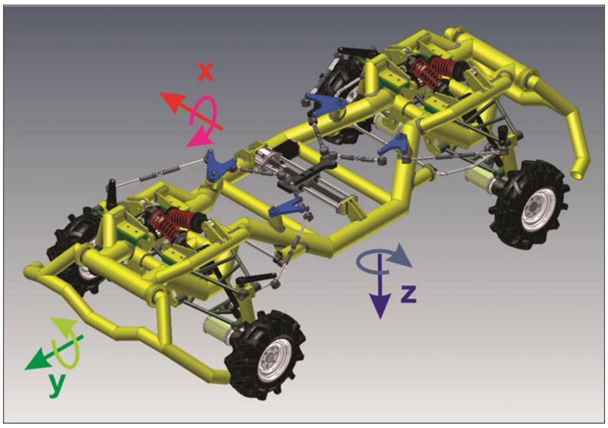
MOMENTS OF RESISTANCE WHEN TURNING THE DRIVE WHEELS WITH THE MOBILE PLATFORM OF THE ROBOT „MNE-ROBECO“

Darko J. Skupnjak, M.Sc.
DAIDO METAL KOTOR AD
Industrijska zona bb, Kotor
Montenegro

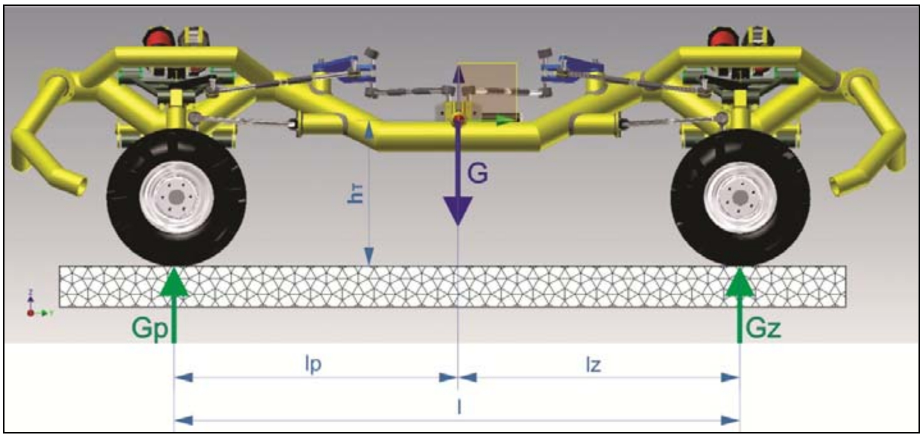
ABSTRACT
The mobile platform for an off-road mobile robot „MNE-ROBECO“ is being developed at the Faculty for Mechanical Engineering of University of Montenegro. This mobile platform moves by four wheels independently driven. The wheels are directed by specially designed spatial mechanism actuated by one motor. The work presents calculation of the moment of resistance when turning the wheels and the motors for driving the wheels and the drive for controlling the wheels turning through control mechanism have been selected.
Keywords: mobile robot, off-road, moment of resistance

1. INTRODUCTION
A mobile platform 4W4D for the off-road mobile robot „MNE-ROBECO“ is being developed at the Faculty for Mechanical Engineering of University of Montenegro . The off-road mobile robot „MNE-ROBECO“ moves using the wheels in order to move along the road. A theory on the road vehicle can be applied to the mobile platform for the robot „MNE-ROBECO“.
For the mobile platform „MNE-ROBECO“, none of well-known types of control mechanism has been used, but the new space mechanism to control direction of wheels of the mobile platform, described in the work [1, 2]. Calculation of mechanism for controlling, of basic mechanism dimensions, and finding conditions of operating stability of the system of control mechanism described in the works [1, 2], basic parameters needed for calculation of necessary torque of servo motor with the gear-box have been determined.

2. AXLE FORCE REACTIONS WITH THE MOBILE PLATFORM
The road vehicle is a complex dynamic system with a large number of degrees of freedom [3, 4, 5]. The body of the road vehicle (the car body with related elements) generally, has 6 degrees of freedom in space, as shown in picture 1 as referred to the mobile platform „MNE-ROBECO“.
Additionally, each of wheels also has 6 degrees of freedom, which makes totally 30 or more [3, 4, 5] degrees of freedom.
Picture 2 shows a frontal view of the mobile platform of the robot „MNE-ROBECO“ with vertical forces and forces and reactions from the platform to the wheels.



Picture1. The mobile platform degrees of freedom



Picture 2: Position of gravity center of the mobile platform and axle force reaction.

Picture 2: G – vehicle weight, G_P, G_Z – shaft reaction of front and rear shaft, l – shaft gap, l_P, l_Z – distance between the gravity center and aggressive lines of the shaft reactions G_P and G_Z, i h_T – height of gravity center.
According to [2, 3, 4], based on statistical conditions of balance, taking into account that $l_P + l_Z = l$, the following can be stated:

$$\left.\begin{aligned} \sum Z_i = 0 \quad &\Rightarrow \quad G_p + G_z = G \\ \sum M_z = \sum M_p = 0 \quad &\Rightarrow \quad G_p \cdot l = G \cdot l_z \end{aligned}\right\} \quad \ldots (1)$$

From (1) we get the following relations:

$$G_z = \frac{l_p}{l} \cdot G \ , \quad G_p = \frac{l_z}{l} \cdot G \quad \ldots (2)$$

For the mobile platform of the robot „MNE-ROBECO“ je: $l_p = l_z = 1/2 \cdot l$, $L = 1,1[m]$, $l_p = l_z = 1/2 \cdot l = 0,55[m]$, $m = 90\ [kg]$, $g = 9,81[m/s^2]$, $G = m \cdot g[N] = 882,9[N]$.
For the case of being static on horizontal ground, the shaft reactions are:

$$G_p = G_z = \frac{1}{2} \cdot G = 0.5 \cdot 882,9 = 441,45\ [N]$$

Reactions of the ground per one wheel are:

$$G_{pt} = G_{zt} = {}^{1}/_{4} \cdot G = 0,25 \cdot 882,9 = 220,725\ [N]$$

For the position of the platform under the angle $\alpha = 45°$, which is the highest possible rake angle the platform can achieve, from statistical conditions of the balance:

$$\left.\begin{aligned} \sum Z_i = 0 \ &\Rightarrow \ G_p + G_z = G \cdot cos\alpha \\ \sum M_A = 0 \ &\Rightarrow \ G_p \cdot l = G \cdot cos\alpha \cdot l_z - G \cdot sin\alpha \cdot \boldsymbol{h}_T \end{aligned}\right\} \quad (4)$$

The following values of the axle force reactions have been got:

$$G_z = 475{,}19\ [N], \quad G_p = 149{,}02\ [N]$$

In case that the front wheels, i.e. the rear wheels are on the same height, reactions for one wheel are as follows:

$$G_{zt} = \frac{G_z}{2} 237{,}56\ [N], \quad G_{pt} = \frac{G_p}{2} = 74{,}51\ [N]$$

3. MOMENTS OF RESISTANCE WHEN TURNING THE WHEELS IN PLACE

Moment of resistance when turning can be determined according to several authors [3, 4, 5]. Formulas for determining moment of resistance of turning the driving wheels in place, based on Mitin and Taborek do not have practical importance [2, 3, 4], so it will not be used here. For determining moment of resistance of turning the driving wheels in place as per Litvinov, it is necessary to know dependence of surface of the pneumatic tires print on their load [2, 3, 4]. As this datum is not known, this method will not be used.

Moment of resistance M_t of turning the driving wheels in place, based on Lisov, [2, 3, 4] is calculated by the following formula:

$$M_t = G_t(0{,}132 \cdot \mu \cdot R_t + f \cdot \rho) \tag{5}$$

where: G_t – vehicle weight applied to one wheel; μ – coefficient of traction of turning the pneumatic tires on the ground; R_t – outer wheel radius; f – coefficient of resistance of the wheels rolling; ρ – angle of rotation of the center of pneumatic tires print, i.e. radius of the wheel turning. On the wheels turning loads are usually pre-set and they are known with accuracy ±(5-10%). Coefficient of friction of pneumatic tyres against the ground (grip) is known and it ranges from 0,7 to 0,9 for dry asphalt or concrete ground.

For the mobile platform for the robot "MNE-ROBECO" the following data are known: the platform mass m_p = 89,7 [kg] (center of the mass lies in plane of the platform symmetry); total platform weight G_{tu} = 880 [N];

Weight applied to one wheel when the platform is horizontal G_t = 220 [N]; μ = 0,8 – coefficient of friction of pneumatic tires turning against the ground; the wheel diameter R_t = 0,1375 [m]; coefficient of resistance of the wheels rolling against the earth road f = 0,2; radius of the wheel turning ρ = 0,0064 [m]. Moment of resistance to the driving wheels turning, according to Lisoc, is as follows:

$$M_t = G_t(0{,}132 \cdot \mu \cdot R_t + f \cdot \rho) = 220 \cdot (0{,}123 \cdot 0{,}8 \cdot 0{,}1375 + 0{,}2 \cdot 0{,}006) = 3{,}26\ [Nm]$$

Moment of resistance M_t to turning the driving wheels in place, according to Gough [3, 4, 5] is calculated using the following formula:

$$M_t = \frac{G_t^{3/2}}{k \cdot p^{1/2}} \tag{6}$$

where: k – empirical coefficient (for common pneumatic tyres is k=2,1); p – pressure in pneumatic tires.

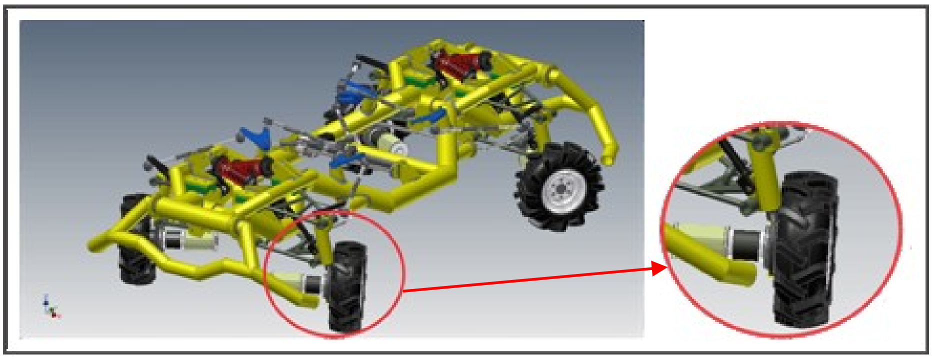
Experimental researches support application of this formula [2, 3, 4].

For the mobile platform for the robot „MNE-ROBECO" the following data are available: the platform mass m_p = 89,7 [kg] (the mass center lies in plane of the platform symmetry), total platform weight G_{tu} = 880 [N]; weight applied to one wheel with the condition that the platform is horizontal G_t = 220 [N], pressure in pneumatic tyres p = 2 [bar]. Moment of resistance to the driving wheels turning, according to Gaugh is:

$$M_t = \frac{G_t^{3/2}}{k \cdot p^{1/2}} = \frac{\sqrt{(220)^3}}{2.1 \cdot \sqrt{200000}} = 3.4747\ [N \cdot m]$$

4. SELECTION OF MOTOR FOR THE MOBILE PLATFORM

Each of four motors has independent drive (figure 3), so that all four motors are required for the drive. In addition to them, another motor is needed for driving mechanism for the wheels control.
Considering that the robot mobile platform carries the car body and other equipment in dependence on the robot purpose use, the motors that can ensure higher platform load have been selected.
For the wheels drive PMDC (permanent magnet DC) motor with planetary gearbox has been selected. The motor characteristics are: 30 VDC, 3300 RPM, In-2,7A, Im-24A, 50W, inductance 3,8mH, Torque 6.75Nm. Planetary gearbox has outer diameter 52mm, transfer relation (6,25:1), and 530 RPM (rotation per minute) . The encoder has input load 5 VDC, impulses per revolution 100-512 ppr, with two channels.
For the move direction control of the mobile platform, one motor with the gearbox which turns the spatial mechanism for the wheels direction is used. PMDC motor with characteristicts: 24 VDC, 3100 RPM, In-1,22A , Im 10,5A has been selected. The worm gear has outer diameter 62mm, (15:1). The encoder has input load 5 VDC, impulses per revolution 100-512 ppr, with the two channels.



Picture 3: Drive of the mobile platform wheels.

5. CONCLUSION

Through calculation of the control mechanism, which has been presented in previous works of the author, basic dimensions of the newly developed spatial gearing mechanism for controlling direction of the mobile platform wheels, as well as other dimensions of the mobile platform necessary for defining required torque of the servomotor with the gear-box have been determined. The purpose of calculation of the parameters for required servomotor with the gearbox is to determine basic parameters ensuring that the control system requirements are met. Calculations have been done in several stages, simultaneously and gradually working on more detailed control system and selection of the best option. Considering that the robot mobile platform is planned to carry the car body and ther equipment in dependence on the robot purpose, the motors that can ensure the platform carrying capacity with high level of safety have been selected.
The mobile platform for the robot "MNE-ROBECO" is being developed at the Faculty for Mechanical Engineering of the University of Montenegro. The project is financed by the Ministry of Science of Montenegro through National "Project of multi-functional service robot "MNE-ROBECO".

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