Experimental Theoretical Study of the Mobile Robotic System Movement with Caterpillar-modular Propulsion on the Beach Line Terrain

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Keywords: AMRC, Modeling, Caterpillar-modular Propulsion, Beach Line Terrain, Adams, ATV, Unmanned Ground Vehicles.

Abstract: This article presents the data for mobile robotic system motion modeling with caterpillar-modular propulsion on the sand support base. The study provides the basics of the development of the calculation model in Adams Tracked Vehicle amid mass and geometric chassis parameters and characteristics of non-rigid soil. The study presents the 3D views of the model created. The study provides the fragments of curvilinear motion. The study provides graphs of behavior moments for chassis beads, as well as shows the total resistance to motion on sandy beach. The mean of the moment on one bead during linear motion amounted to 172 Nm, during curvilinear 195 and 217 Nm respectively for backward and overleaping chassis beads. The mean resistance to motion during linear motion amounted to 1606 N, during curvilinear to 1943 N. To validate the results of the modeling we have conducted experimental studies.

1 INTRODUCTION

The monitoring of beach line terrain can be done with the help of fixed stations, research equipment can be installed on a special mobile robotic system (Barber and Mills 2007, Belyakov et al. 2017, Bio et al. 2015, Didier et el. 2015, Incoul et al. 2014, Kramer and Hunter 2007, Kurkin et al. 2015, 2017, Serra et al. 2005, Wübbold et al. 2009, Zaytsev at. al 2017).

To solve the issue of providing movement for mobile robotic systems, it is necessary to choose chassis with the most suitable parameters for operating conditions, as well as for the requirements of the attached list of active jobs.

Depending on the issues needed we can use a different mathematical apparatus for modeling motion and interaction of propulsions with the surface lane. One of the ways is the imitational modeling using the MSC.ADAMS program. However, a test on the real-life object is needed to confirm calculations. This object is the autonomous mobile robotic system created at the Nizhny Novgorod State Technical University n.a. R.E. Alekseev (Belyakov et al. 2017, Kurkin et al. 2015, 2017, Tyugin at. al 2018, Zaytsev at. al 2017). The unique feature of AMRC is the possibility of installation wheel, caterpillar-modular and rotary-screw propulsion. This article presents the issue of chassis motion modeling with modular-caterpillar propulsion.

2 THEORETICAL RESEARCH

To study AMRC we used a special application in the Adams environment, which allowes to model vehicles on caterpillar tread. Using Adams Tracked Vehicle (ATV) we created the design of caterpillar machines, as well as modeling of their movement with different speeds on rigid or non-rigid soil.

2.1 Assumptions

The study have implied the following assumptions:

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Belyaev, A., Papunin, A., Zharkov, E., Vasiliev, A., Belyakov, V. and Makarov, V.
Experimental Theoretical Study of the Mobile Robotic System Movement with Caterpillar-modular Propulsion on the Beach Line Terrain.
DOI: 10.5220/0009794705670572
In *Proceedings of the 6th International Conference on Vehicle Technology and Intelligent Transport Systems (VEHITS 2020)*, pages 567-572
ISBN: 978-989-758-419-0

- body, road rollers, tracks assumed to be in the shape of completely rigid bodies;
- caterpillar thread consists of tracks, interconnected by force interaction;
- tracks, road rollers have contact interaction with support base;
- support base is described using the Becker's model;
- soil pickup on the propulsion is absent;
- the control of the movement trajectory implemented using the PID regulator, where the input signal is the distance between the set movement trajectory and a «checkpoint» on the caterpillar machine body, and the output signal – turning moment on the crawler wheels.

2.2 Movement Model

Software package MSC.ADAMS designed to address the problem of rigid body dynamics and uses the system of differential-algebraic equations. The base for the equation system, describing the dynamic of system n of rigid bodies,under the influence of m stated force and limited m holonomic constraints, is made in the form of Euler-Lagrange equations with multipliers.

Euler's equations for forward running:

$$\begin{aligned} m\, dV_x/dt &= \sum F_x \\ m\, dV_y/dt &= \sum F_y \\ m\, dV_z/dt &= \sum F_z \end{aligned} \tag{1}$$

Euler's equations for rotary movement:

$$\begin{aligned} I_x\, d\omega_x/dt + (I_z - I_y)\omega_y\omega_z &= M_{Ox} \\ I_y\, d\omega_y/dt + (I_x - I_z)\omega_x\omega_z &= M_{Oy} \\ I_z\, d\omega_z/dt + (I_y - I_x)\omega_x\omega_y &= M_{Oz} \end{aligned} \tag{2}$$

2.3 Machine Model Design in ATV

AMPK consists of the body and four caterpillar modules, consisting of track suport roller, the crawler wheel and caterpillar track.

The body has geometric paramenters and mass-inertia characteristics. Apart from the mass and moments of body inertia, relative to the main axes, the coordinates of the location of gravity center are preset.

The crawler wheels with the radius of 215 mm. bring in motion caterpillar encircling using the toothing with caterpillar tracks. The toothing of the crawler wheel and tracks is done using contact interaction with each of the tracks of caterpillar encircling. In figure 1 (left) shown the visualisation of crawler wheels.

Caterpillar encircling of each module consists of 29 tracks at 99 mm. intervals. Figure 1 (right) shows track visualization.

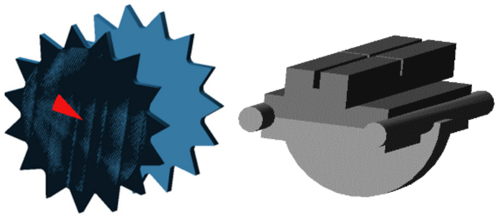

Figure 1: Crawler wheel and track visualization.

As a result of chassis development in ATV environment we obtained the following view of AMRC. Figure 2 presents the side view and 3/4.

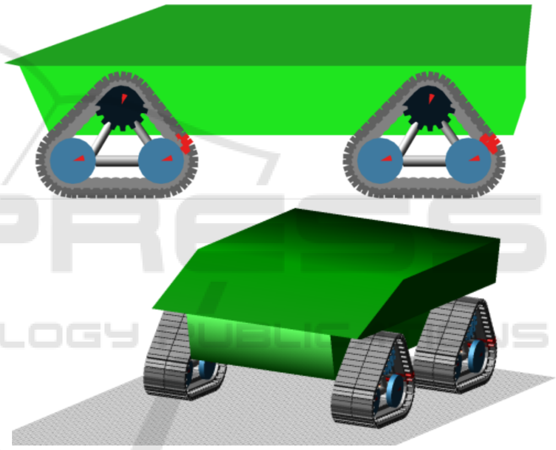

Figure 2: AMRC model in ATV. Side view and 3/4.

2.4 Non-rigid Support Base Design in ATV

Non-rigid soil model has a «memory» and keeps a history of loading. In ADAMS programming system Tracked Vehicle model nonrigid soil visualized in the shape of rectangular net, where each element has a history of loading.

The process of design non-rigid support base in ATV programming system narrows down to choosing a property file soil (Ageykin et al., 2010, Ageykin and Volskaya, 2003, 2008, Bekker, 1960, Wong, 2010) with preset characteristics from database.

Property file of non-rigid support base is made as a set of experimental evidence coefficiencies, describing one or another soil type. Figure 3 presents an example of popup window, which contains the coefficients, necessary for description of parameters of vertical, lengthway and side force between supporting base and caterpillar chain track.

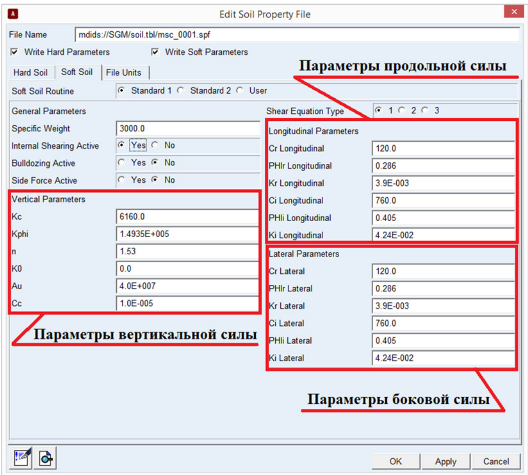

Figure 3: Coefficients necessary for description force interaction non-rigid support base and caterpillar chain track.

AMRC views on nonrigid soil are shown in Figure 4.

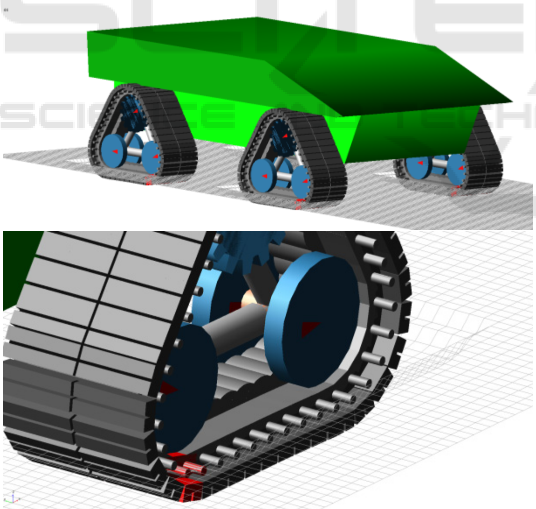

Figure 4: AMRC on non-rigid soil.

2.5 AMRC Motion Modeling in ATV

For the designed AMRC model we have conducted a motion modeling on bearing surface with characteristics close to a sand surface beach line terrain. The modeling have studied two types of motion: linear and 180 degree turning with turning radius to chassis center equals to 5 meters.

Figure 5 demonstrates the fragments of curvilinear motion.

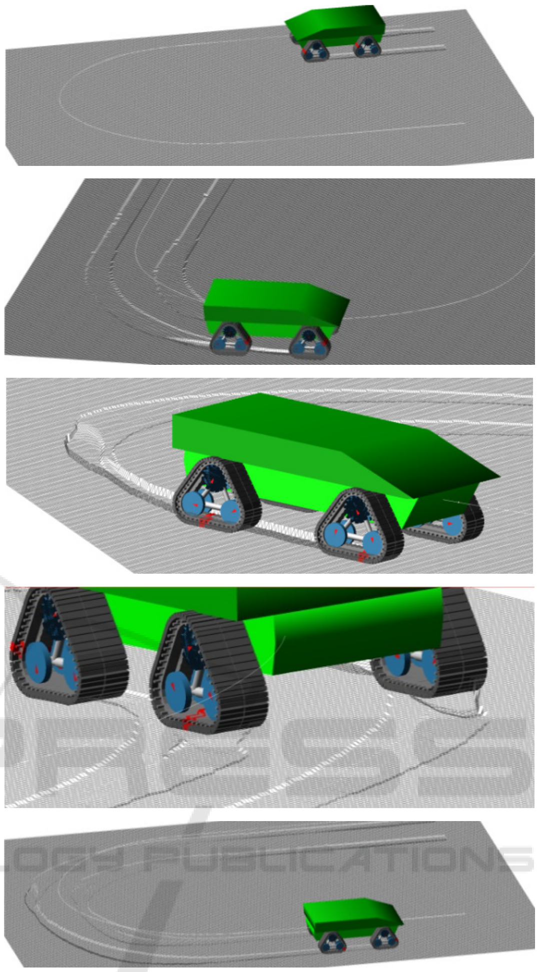

Figure 5: AMRC curvilinear motion.

As a result of turning on linear and curvilinear trajectory we obtained the graphs of turning moment and power on main crawler wheels. We obtained the values for wheel spinning. The maximum motion speed was preset at 25 km/hr.

Figure 6 (top) demonstrates examples of turning moment changes on the main wheels of caterpillar modules of one bead during linear motion. In figure 6 (bottom) shown the moments on main wheels of caterpillar modules during the turn.

On grahs in figure 6 (bottom) positive values correlate to moments on the outside of AMRC, negative on the inside. The mean of moment on one bead during linear motion amounted to 172 Нм, during curvilinear to 195 и 217 Nm respectively for backward and overleaping chassis beads.

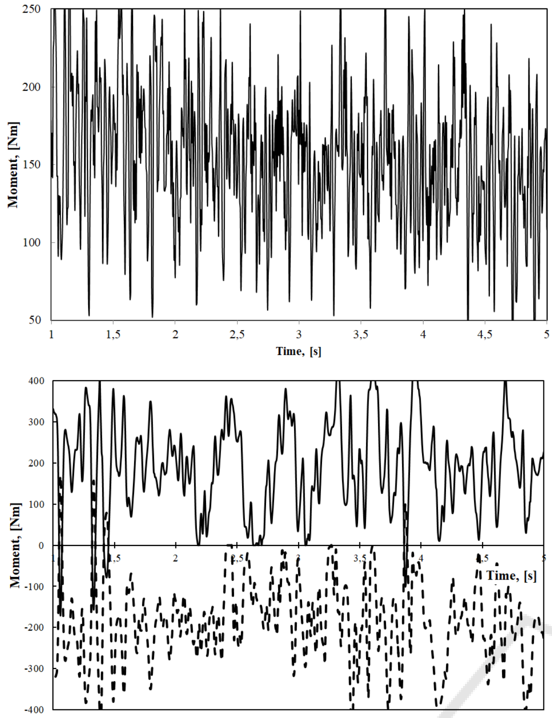

Figure 6: Turning moment behavior graphs.

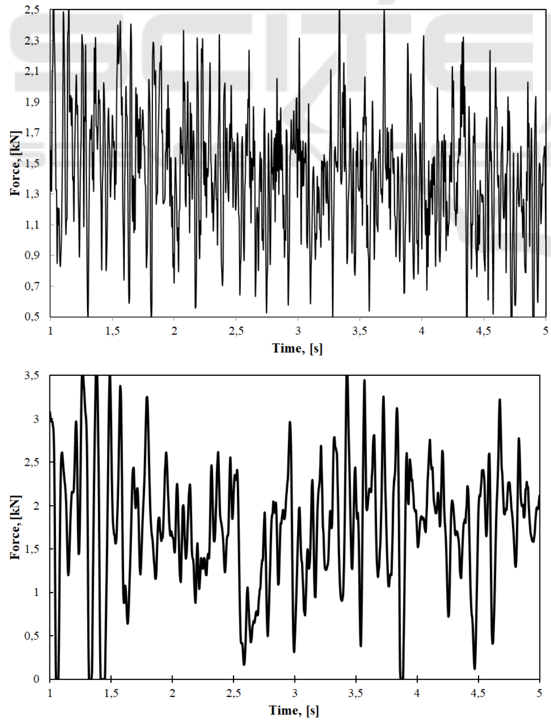

Figure 7: Behavior graphs of motion resistance force of AMRC on the sand.

Figure 7 present the change of motion resistance force of linear motion (top) and curvilinear (bottom) motion. The mean for linear motion amounted to 1606 N, for curvilinear to 1943 N.

The evidence correlates to conducted experimental studies.

Figure 8: Experimental studies fragments.

3 THEORETICAL RESEARCH

For choosing input data for modeling we have conducted experimental data for sampling of AMRC motion resistanse and parameters of support ground. (Belyaev et al., 2018, 2019 Kurkin et al., 2017, Makarov et al., 2017) Figure 8a shows AMRC motion moment alongside shore line. Figure 8b shows a sampling fragment of resistance force. An additional vehicle pulled AMRC through the wire rope with load cell. Figure 8c demonstrates the moments of sampling physicomechanic characteristics sand shore. The left side demonstrates the sampling of resistance of penetration, the right - soil density.

From the data received we have obtained soil characteristics included in soil model in ATV. The mean motion resistance amounted to 1600 N (Belyaev et al., 2018, Belyaev & Makarov, 2018). These data was used for model checkout during AMRC linear motion.

4 CONCLUSIONS

The study presented basic motion equations used in MSC.ADAMS for machine modeling motion.

The study lists the assumptions used in the model.

The study designes the AMRC model with caterpillar-module propulsion.

We have obtained the modeling of linear and curvilinear AMRC motion on sand support base.

The results include model parameters behavior graphs in time. As a result, the mean of moment on one bead during linear motion amounted to 172 Nm, during curvilinear to 195 and 217 Nm respectively for backward and overleaping chassis beads. The mean of motion resistance during linear motion amounted to 1606 N, during curvilinear to 1943 N.

The experimental studies present the sampling of resistance force on the real-life object at beach line terrain. The mean motion resistance amounted to 1600 N.

Amid the experimental data findings adjustments were made to the model of interest.

The future studies include modeling of on-the-spot machine turn, the movement on other types of support bases, the evaluation of operational efficiency at beachline terrain.

ACKNOWLEDGEMENTS

The results of the given study have been obtained with financial support of the grants of the President of the Russian Federation № MD-226.2020.8.

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