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Simulation Modeling of Random Change of Ground Surface Characteristic during Military Tracked Vehicle Motion

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This article is dedicated to the study of the simulation modeling of random external perturbation influence on the military tracked vehicles motion, including accidental changes of the ground surface characteristics. Despite the significant amount of work done on the subject, the modeling of the ground surface characteristics changes needs additional consideration. Based on the inverse–transform method, this article proposes an algorithm to obtain an array of random coefficients of resistance to the linear motion and rotation. The results show that the algorithm can improve the accuracy of the simulation of tracked military vehicles perturbed motion and could be useful for studies aimed at improving the transmission elements and power units of military tracked vehicles.

Keywords: military tracked vehicle, simulation, resistance coefficients, distribution function, algorithm, the inverse–transform method.

1. Introduction

One of the modern methods applied in development and modernization of weapons and military equipment is simulation modeling. The use of the simulation allows to reduce the scope and expenses of project works. The essential problem of simulation is the adequate representation of stochastic perturbation affecting the modeling object that can significantly improve the efficacy and the accuracy of the simulation model.

Development of hydrostatic steering drive for military tracked vehicles requires simulation of track–laying curvilinear motion of the vehicle whereby one can study forces and moments which have an effect on military tracked vehicle. In this case simulation modeling of stochastic perturbation allows to correct forces and moments, required for curvilinear movement of the tracked vehicle.

The simulation modeling of stochastic perturbations occurring during tracked vehicle motion has been examined in a number of publications dedicated mostly to studying the influence of surface microprofile on a cushion system and vibratory stress of the system [2, 3, 7, 10, 11, 16]. The articles [1, 5, 9] aimed at the analysis of the surface microprofile influence on force and velocity parameters of propulsion engine. The article [8] is dedicated only to the surface microprofile simulation without applying it to the solution of some technical problems. Researches performed in above mentioned papers do not take into consideration a random change of the surface characteristics during the tracked vehicle motion. However it is known that the changing of surface characteristics affects dynamic properties of a vehicle [4, 6]. It is necessary to consider this during a simulation of the tracked vehicle motion while studying drive and propulsion engine parameters.

The main goal of this paper is simulation of random changes of ground surface characteristics during military tracked vehicle motion.

2. Modeling of external disturbances of the ground surface

Let us assume the military tracked vehicle is moving with the linear velocity υ and the angular velocity ω. Resistance forces that act on the vehicle during the motion determine the scale of the motive force which is required to sustain the motion (Fig. 1) [15].

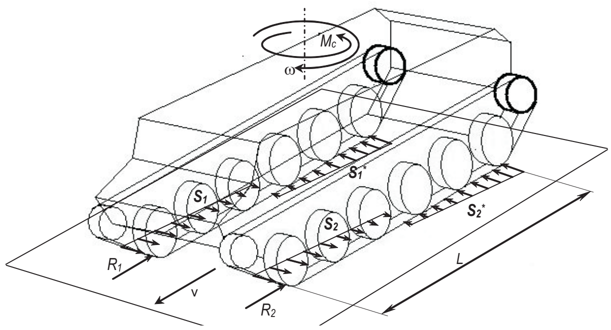

Figure 1

The resistance forces to the forward motion of the military tracked vehicle R_1 and R_2 directly depend on f – a coefficient of resistance to the rectilinear motion of the vehicle:

$$R = fN \tag{1}$$

where N is the overall reaction of the ground surface.

The resistance torque M_c is determined by value of sideforce reactions S_1, S_2, S_1^*, S_2^* and by length of L baseline of the military tracked vehicle:

$$M_c = (S_1 + S_2 + S_1^* + S_2^*)\,\frac{L}{2} \tag{2}$$

The sideforce reactions, in return, directly depend on a coefficient of turning resistance μ [14]:

$$S_1 = S_2 = S_1^* = S_2^* = \mu\frac{G}{4} \tag{3}$$

Consequently, it means that random variation of resistance coefficients of the rectilinear motion f and turn μ determines random variation of reactions R_1 and R_2 and the resistance torque M_c which have to be overcome:

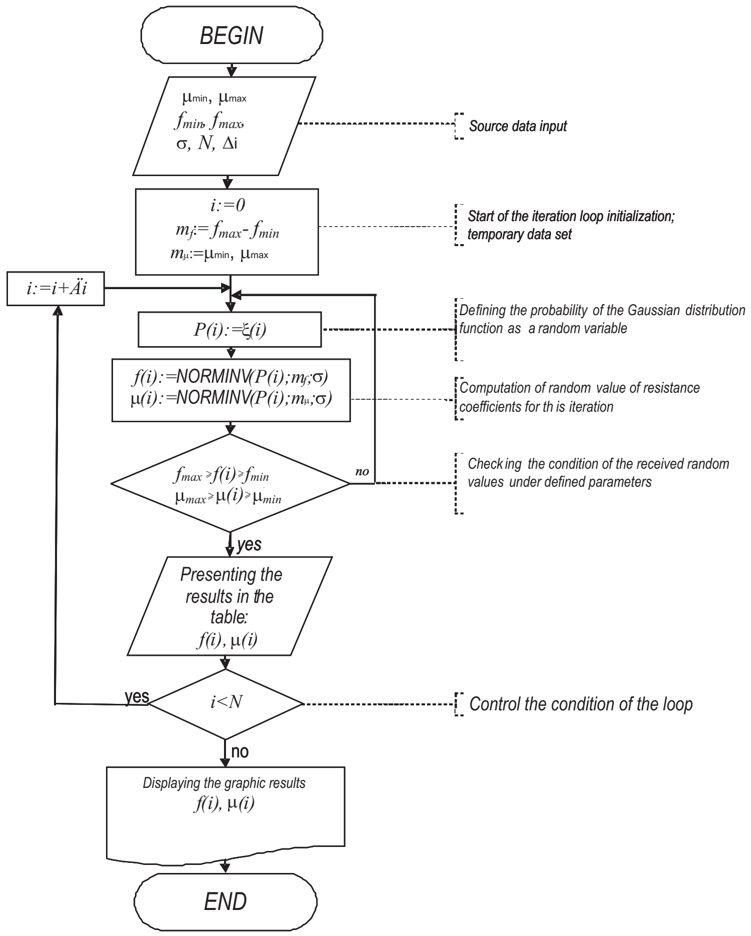

Figure 2

It is known from the papers [6, 15] that the resistance coefficients of the rectilinear motion f_n and the turn μ_{max} of a tracked vehicle are values which are obtained by an experimental approach. Therefore we do not need to perform a simulation of the ground surface microprofile, because we cannot rule out the possibility that at the time of obtaining experimental data the microprofile will interfere with empirical coefficients determination. Hence during the modeling of external perturbation influences on the forces and torques required for the motion it is sufficient to simulate the random changing characteristics of the ground surface.

Let us construct an algorithm for obtaining an array of random values of resistance coefficients of the rectilinear motion and the turn (Fig. 2).

Analysis of numerous experimental data shows that the variation of the resistance coefficients of the rectilinear motion f_n and the turn μ_{max} follows the Gaussian distribution law [14], i. e.:

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{x - m_x}{2\sigma^2}\right) \tag{4}$$

where x is the coefficient f_n or μ_{max}.

In this case the probability density function of resistance coefficients of the rectilinear motion f_n and the turn μ_{max} could be completely defined by a standard deviation σ with statistical expectation m_x. Its values are recorded in the Tab. 1.

Table 1 Characteristics of the probability density function for resistance coefficients of the rectilinear motion and the turn of a military tracked vehicle

Ground surface condition	Statistical expectation m_f	Statistical expectation m_μ	Standard deviation σ
Hard-surface roads	0,035 – 0,045	0,3 – 0,5	0,0055
Gravel roads	0,05 – 0,055	0,8	0,007
Hard unpaved roads	0,07	0,8	0,009
placeBrocken unpaved roads	0,0675	0,8	0,015
Rough terrain	0,06 – 0,25	0,6 – 0,96	0,0225

The statistical expectations values m_f and m_μ are arithmetic means for the upper and the lower bounds of the table values of corresponding coefficient for a selected ground surface condition. The dependence of resistance coefficients of the rectilinear motion and the turn on the soil type is shown in the Table 2 [6, 15, 16].

To obtain an array of random values for resistance coefficients of the rectilinear motion f_n and the turn μ_{max} we can use the inverse transformation method (Smirnov transform) [13]. For this purpose, let us take an inversion of the integral spectral density function, or distribution function

$$F(P) = \frac{1}{2} + \frac{1}{\sqrt{2\pi}} \int_0^t \exp\left(\frac{t^2}{2}\right) dt = \frac{1}{2} erf\left(\frac{P - m_x}{\sigma\sqrt{2}}\right) \tag{5}$$

where $t = \frac{P - m_x}{\sigma}$, x is the resistance coefficient f_n or μ_{max}.

Table 2 The dependence of resistance coefficients on surface characteristics

Surface characteristics	Resistance coefficients of the rectilinear motion f_n	Resistance coefficients of the turn μ_{max}
Bituminous concrete surface (class I)	0,035 – 0,045	0,4 – 0,5
Bituminous concrete surface (class II, III)	0,04 – 0,05	0,4 – 0,5
Dry smooth pavement	0,045 – 0,055	0,75 – 0,85
Mediocre pavement	0,05 – 0,06	0,75 – 0,85
Dry graded unpaved road	0,06 – 0,08	0,7 – 0,9
Dry broken unpaved road	0,065 – 0,07	0,7 – 0,9
Unpaved road in break-up season	0,1 – 0,15	0,3 – 0,5
Traffic-bound road under snow	0,06 – 0,08	0,12 – 0,22
Iced snow road	0,05 – 0,1	0,25 – 0,35
Ice road	0,03 – 0,04	0,45 – 0,55
Dry turf-grass soil	0,05 – 0,07	0,7 – 0,9
Dry sandy soil	0,1 – 0,25	0,8 – 0,9
Wet sandy soil	0,08 – 0,1	0,9 – 1,1
Dry turf-grass loam	0,07 – 0,09	0,8 – 1,0
Dry dusty loam	0,06 – 0,08	0,7 – 0,9
Dry mown grass	0,08 – 1,0	0,7 – 0,9
Wet mown grass	0,1 – 0,16	0,9 – 1,1
Harvested field	0,06 – 0,08	0,55 – 0,65
Plow field	0,1 – 0,16	0,6 – 0,8
Virgin snow	0,15 – 0,25	0,5 – 0,7
Swampland	0,2 – 0,3	0,85 – 0,9

The distribution functions of the resistance coefficients are shown in Fig. 3 and Fig. 4.

We need to modify a random array generator of numbers uniformly distributed by ξ(i) on the interval [0, 1]. The modification could be provided during construction of the inverse function of the normal distribution by using the random values as a probability index. To obtain the array of random values of the resistance coefficients we have used the function NORMINV($P,\ m_x,\ \sigma$) of the Excel software.

Since the generated resistance coefficients in some cases can exceed the limits defined by the tabular conditions (Table 2), the algorithm specifies re-generating of the random values $\xi(i)$ until obtained values do not satisfy the conditions:

$$f_{max} \geq f(i) \geq f_{min}$$
$$\mu_{max} \geq \mu(i) \geq \mu_{min}$$

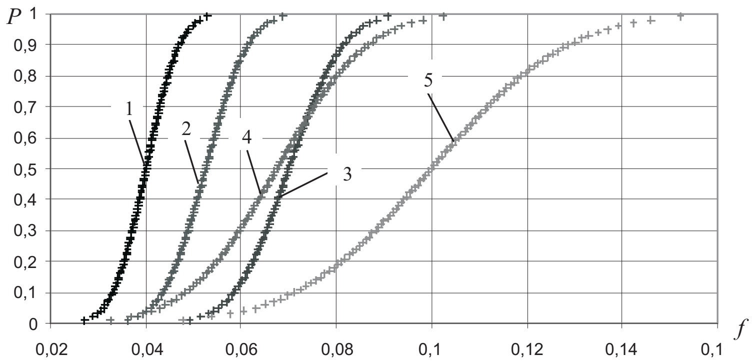

Figure 3

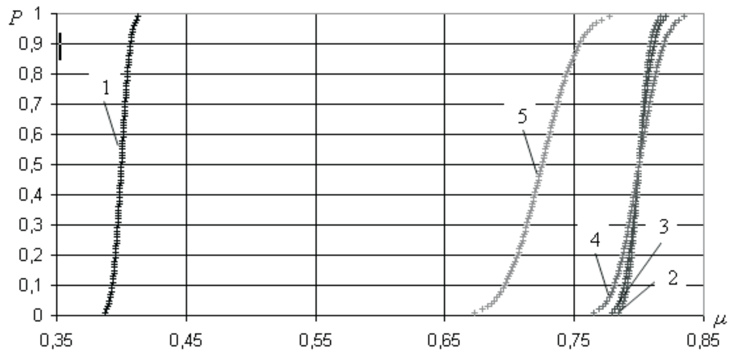

Figure 4

Taking as an example the algorithm proposed at Fig. 2 with the help of Excel software environment we can obtain required arrays of random resistance coefficients of the rectilinear motion f_n and the turn μ_{max} in a dry sandy soil for 1000 iterations.

When we obtain a new random value in each next iteration we can simulate a random changing of the surface parameters on which tracked vehicle moves. This allows us to adjust the existing simulations of perturbed motion of a military tracked vehicle. During the application of this algorithm to simulate the forces and the moments which are required for a curvilinear motion of a military tracked vehicle, in order to improve the adequacy of the simulation model it was deemed necessary to parallel simulate the resistance coefficients for the right and the left tracks independently. Utilization of the mathematical representation [12] allows us to obtain the values of torques M1 and M2 at the driving wheels which are required for 42-ton tracked vehicle movement on dry sandy soil with a speed of 25 kilometers per hour (Fig. 7, 8), and to compare the data with the results of simulation M1(f-const), M2(f-const), when the constant values of resistance coefficients f and μ are taken as the arithmetic mean of tabular values of this coefficients.

The comparison of torque moments obtained through mathematical modeling and simulation modeling (Fig. 10) allows us to conclude that the difference between them during a perturbed curvilinear motion on the slope in some cases could reach 7 kilonewton-meters. It indicates an increased adequacy of the simulation model compared with the mathematical model.

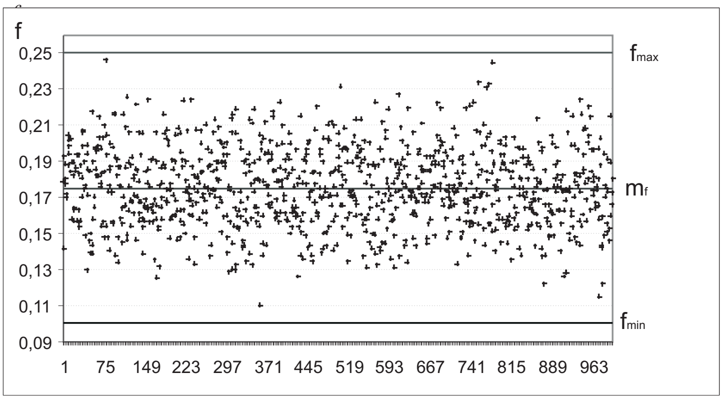

Figure 5

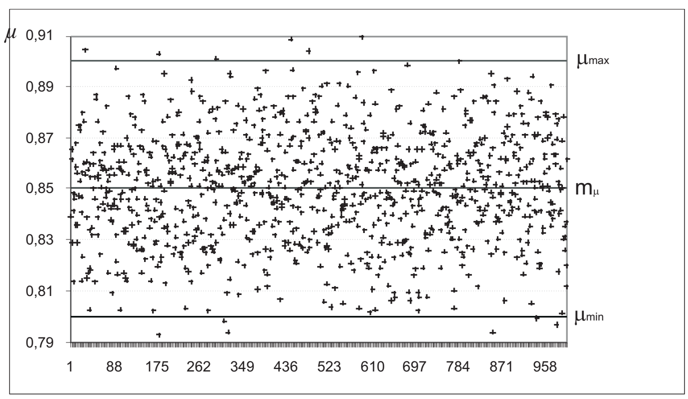

Figure 6

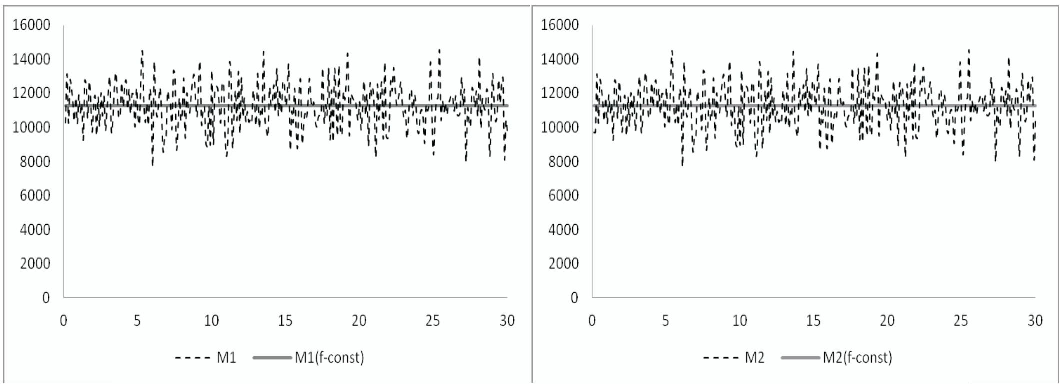

Figure 7

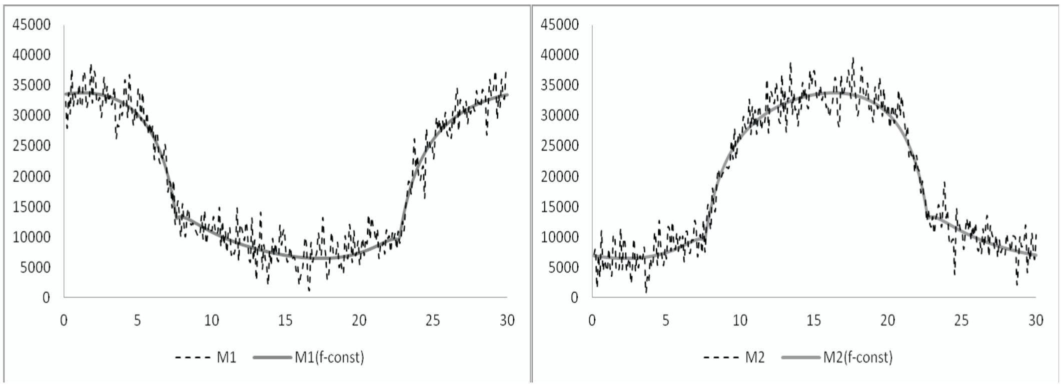

Figure 8

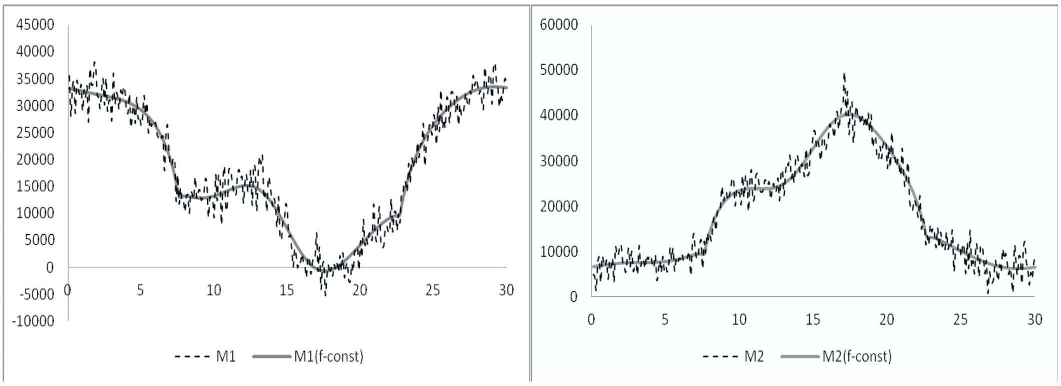

Figure 9

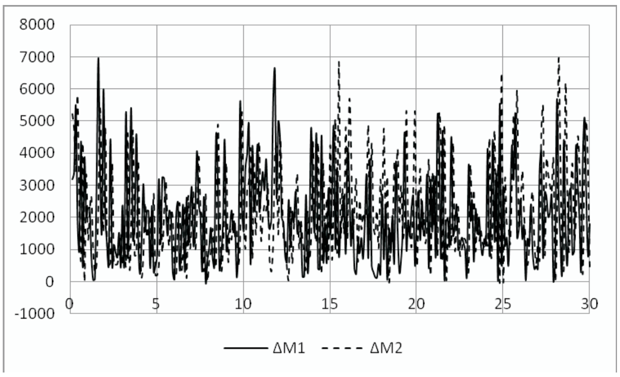

Figure 10

3. Conclusions

1. Existing simulation models of external disturbances influencing the military tracked vehicle during motion are aimed at modeling of microprofile surface only, and do not take into account accidental changes of the surface. This approach is acceptable while studying machine body oscillations, but at the same time it is not accurate enough in the case of the study of the external disturbances impact on power and kinematic parameters of the drive and the propulsion engine.

2. In this article we propose the algorithm for constructing an array of normally distributed random resistance coefficients of the rectilinear motion and the turn of a military tracked vehicle, which values are used during the simulation modeling of a tracked vehicle motion.

3. The proposed algorithm improves the adequacy of the simulation model of a military tracked vehicle perturbed motion without increasing its complexity, due to the resistance coefficient values, which take into account parameters of supporting surface microprofile.

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