Predicting modeling of the service properties of carrying systems in the articulated-vehicle-based self-propelled artillery systems

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Abstract. The work is devoted to the possibility and prospects of the use of articulated-vehicle-based self-propelled artillery systems in order to increase their effective firing rate abilities. The reasons for creating such systems are presented. A mathematical model and its description are given. The high convergence of the analytical and the experimental data shows the adequacy of the established mathematical model. The use of the articulated-vehicle construction in self-propelled artillery systems makes it possible to reduce the time between two shots by about 2.5 seconds. Work conditions of the crew are also substantially improved.

1. Introduction

The economic situation in the country and the political situation in the world sets tasks for the designers and manufacturers of self-propelled artillery, the solution of which will, on the one hand, provide a high degree of tactical, operational-tactical and strategic mobility, increase the firepower of self-propelled artillery pieces, and on the other hand, create products competitive in the world market.

One of the competitive advantages is the maximum customization of the products to the conditions of the buying country. Potential buyers of self-propelled artillery pieces are the countries of the Middle East. The conditions in which the equipment will be operated imply the use of wheeled running gear, which will undoubtedly increase the mobility of the machines [1,2].

The ammunition load of a self-propelled artillery piece (SPAP) is limited. An increase in it can be provided by the creation of articulated systems as part of SPAP and a loader vehicle, the ammunition load of which is three times higher than that of a single vehicle.

The effective rate of fire of SPAP largely depends on the time that elapses from the moment of the shot until the stop of hull oscillations and aiming recovery [3]. To achieve it, the elastic suspension elements must, on the one hand, perceive and damp the recoil energy from the shot, and on the other hand, have a high degree of dissipation to damp oscillations when the system is moving over the terrain [4, 5].

Ural State Federal University in conjunction with the central design bureau (CDB) Transmash has developed a complex mathematical model of the articulated vehicle-based SPAP which allows considering the SPAP-body oscillation process after the shot both for the SPAP as a single unit and in
tandem with loader vehicle. Mathematical model also allows to determine a suspension parameters and elastic characteristics of the articulation joint that are required for increasing the effective rate of fire. If the SPAP-layout includes a loader vehicle, the mathematical model helps to estimate to what degree the oscillation damping time is affected by the presence of the second section (loader vehicle).

2. Theoretical part
The construction under consideration is characterized by a number of elastic constraints, control and self-adjustment elements and also by an accidental character of external and its internal forces [6]. The suggested approach allows to change the step of integration for each differential equation depending on motion character of any object without increasing the resources used, thus improving the quality of studied model significantly [7, 8].

Motion equation of the system:

\[ \Theta \ddot{\Theta} = F + R, \quad (1) \]

where

\( \Theta \) - canonical coordinates for inertia forces;
\( \dot{\Theta} \) - inertia coefficients in the direction of canonical coordinates;
\( F \) - external forces reduced to canonical coordinates;
\( R \) - reduced internal forces;

The equation (1) can be represented in form of the tripartite graph (figure 1).

The graph defines the structure of the program during the integration of the system. In accordance with the graph structure it is required to elaborate the connections and the tops of the middle lobes of the graph. The scanning of the connections of the graph should be performed primarily between the middle and the left lobe, then between the middle one and the right one.

The interaction between the middle lobe tops is carried out in the conditions described in the left lobe. The internal action forces R represent a general class [9-11]:

![Tripartite graph for the motion equation](image)

**Figure 1.** Tripartite graph for the motion equation
The figure 2 (a, b) represents the analytical model of the first and the second section of the articulated vehicle-based SPAP [12, 13]. On the figure 2 the force $P$ represents the load on the trunnion pin from the gun during the shot. The force vector direction can change up to 360° about a $Z_1$ axis. During tactical operations a firing sector is considerably narrower and changes in a range of ±45° about $Z_1$ [11].

Figure 2. Analytical model of the articulated vehicle-based SPAP: a – first section (SPAP); b – second section (loader vehicle).

The interaction between the SPAP and the ground is carried out through the suspension elastic elements [14, 15]. As mentioned above, the running gear used in these type of vehicles is a wheeled running gear [16, 17]. On the figure 2 four support points are shown at every section. In the mathematical model the number of such points is not limited though.
The number of degrees of freedom of the real articulated vehicle-based SPAP is infinite. In order to mathematically describe a motion process of such system one should analyse a motion of the first and the second section separately. The coupling between the two sections should be substituted by an interaction force. When in motion, the connection between the two sections can be considered as rigid and when firing – as elastic. On the figure 2b this connection is represented by the elastic element with a coefficient of rigidity «с» and dissipation coefficient «k».

3. Experimental part

On the figure 3 is representing the diagram that shows displacements of the center of mass (CM) of the SPAP-bodies after the shot. In ordinate axis direction the CM-displacements along the longitudinal axis of the SPAP are shown. The abscissa axis represents time [10, 11].

![Figure 3](image)

**Figure 3.** SPAP-bodies displacements after the shot and CM-acceleration of the first section: green – CM-displacement of the first section; red - CM-displacement of the second section; gray – CM-acceleration of the first section. (division value of the absciss axis – 0,5 s, the same for the ordinat axis – 0,075m)

4. Conclusion

The high convergence of the theoretical and experimental data allows for a conclusion that the established complex mathematical model can be used for an analysis of the SPAP-body oscillation process in case of its coupling with a loader vehicle, i.e. as an articulated vehicle-based SPAP.

The results of resolving of the mathematical model for an 2C19-SPAP in conjunction with the ТЗМ334-unit have shown that the oscillation decay time after the shot has been significantly reduced: depending on a gun position, in average by 2,5 seconds. Acceleration magnitude at the commander’s and the driver’s sit is reduced by 20% in average.

As a result the use of the SPAP in tandem with the loader vehicle enables to create an articulated vehicle-based SPAP with enhanced firing performance.

Using the simulation modeling of the SPAP-bodies behavior allows to provide a parameters of the elastic and dissipative elements of the SPAP- and loader vehicle-suspension that enable on the design stage the prediction of the behavior of the SPAP-bodies after the shot and when in motion over the terrain, thus reducing the testing time required for creating a new units.

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