THE DYNAMIC CALCULATION MODEL OF LAUNCHER ON COMBAT VEHICLES USING HYDRAULIC JACKS ON ELASTIC GROUND

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Abstract: *In this paper, a dynamics model of a launcher on a combat vehicle using hydraulic jacks is established. Theoretical foundations of multi-object mechanics are used to set up mathematical equations describing the vibration of a launcher when firing. The ground in the surveyed model is considered as an elastic element with K hardness and viscous drag coefficient C. The research results are applied to calculate the BM14 combat vehicle, the stability of the BM14 launcher when single and multiple fired is specifically surveyed in the following cases: Using hydraulic jacks, the ground is considered to be inelastic; Using hydraulic jacks, BM-14 combat vehicle is placed on the elastic ground; Without using hydraulic jacks, BM-14 combat vehicles are placed on the elastic ground. Survey results show the reliability of the launcher when firing. The content of the paper is a theoretical basis to contribute to the process of improvement, design, manufacturing, and exploitation of combat vehicles that use hydraulic jacks with high efficiency.*

Keywords: Hydraulic jacks; BM-14 multiple launch rocket system; Vibration of the launcher.

1. INTRODUCTION

Multiple launch rocket system is one of the most important artillery systems in the army of nations around the world. The salient features of multiple launch rocket systems are simple structure, fast maneuverability, convenience in use, high operational reliability, and strong power. Therefore, it is commonly used in the world. About structural characteristics, multiple launch rocket system is often mounted on tires to increase maneuverability in combat so the accuracy of the launchers is reduced. To increase the accuracy of the launchers, hydraulic jacks have been equipped for combat vehicles to eliminate the elasticity of the wheels when firing.

The BM-14 multiple launch rocket system (figure 1) is one of the typical firepowers for installing rocket launchers on rubber tire vehicles using hydraulic jacks during firing. The launcher is acted by forces such as the gravitational force, the exhaust gas force, the dynamic loads when fired, so the vibration of the launcher in space is complex vibrations. These vibrations create deviations in the traversing angle and elevating angle, because of reduced firing accuracy. There have been many studies on the vibration of the launcher. However, those studies did not mention the stability of the launcher mounted on rubber tire vehicles that used hydraulic jacks when fired.

The paper has established the dynamic model of the launchers mounted on combat vehicles using hydraulic jacks. The studying results are the theoretical basis for evaluating the effectiveness of using hydraulic jacks for rubber tire vehicles.

2. ESTABLISHING CALCULATION MODEL

2.1. Assumptions

To establish the BM-21 combat vehicle model according to the multi-object mechanic's theory, some assumptions are used to simplify the calculation process as follows:

- Details and detail assemblies are considered absolute solids;

- The wheels are replaced by linear elastic elements, viscous bumpers and pointing vertically;

- The ground is flat, the drag and friction forces are evenly applied to the wheels;

- The symmetry axes pass through the center of each object;

- The tweezers are linear elastic, viscous and only vertical;

- The displacements are oscillations that are considered small:

$$\sin(q) \approx q \,, \cos(q) \approx 1$$

2.2. Establishing the mechanical model

From the above assumptions, the model of BM-14 combat vehicle is established as shown in figure 1.

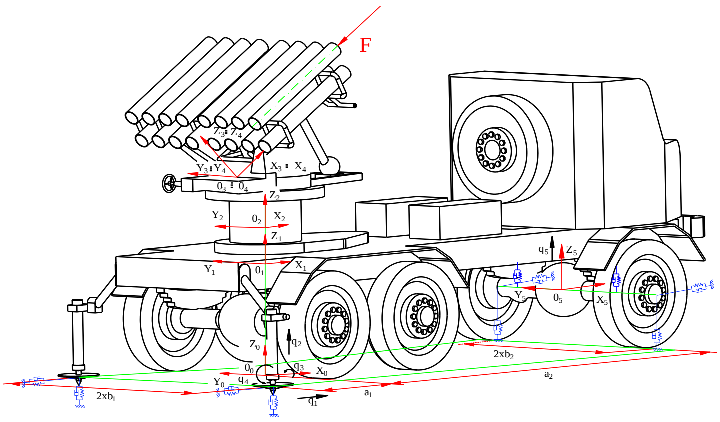

Figure 1. *The model of BM-14 combat vehicle.*

The investigated system consists of 5 bodies:

- Object 1: Vehicle object and rear axle. The object 1 has: mass m_1, the center of gravity at C_1, the moment of inertia of object 1 to focus C_1 is I_1; Object 1 is connected to the ground by two hydraulic jacks at the object back, connected to the front axle through two tweezers left and right, connected to the traverser part through the traversing mechanism.

- Object 2: Traverser part. Object 2 has: Mass m_2, the center of gravity at C_2, the moment of inertia traverser parts to focus C_2 is I_2; Object 2 is connected to the elevation part through the elevating mechanism and connected to object 1 through the traversing mechanism.

- Object 3: Elevation part. Object 3 have: Mass m_3, the center of gravity at C_3, the moment of inertia of object to focus C_3 is I_3; Object 3 is connected to the remaining rocket by a brake mechanism.

- Object 4: The remaining bullets part. Object 4 has: Mass m_4, the center of gravity at C_4, the moment of inertia of object to focus C_4 is I_4; (These parameters are changed after each fired).

- Object 5: The whole front axle. Mass m_5, the center of gravity at C_5, the moment of inertia of object to focus C_5 is I_5.

2.3. The coordinate system

- Fixed coordinate system $R_0 = \{O_0\ X_0\ Y_0\ Z_0\}$: O_0 is the intersection point of the axis of traversing rotation with the ground plane;
- Coordinate system $R_1 = \{O_1\ X_1\ Y_1\ Z_1\}$: O_1 is the intersection of the rotating axis with a fixed roller plane mounted on the bottom carriage;
- Coordinate system $R_2 =\{O_2X_2Y_2Z_2\}$ is the coordinate system of the object 2, R_2 coincides with R_1;
- Coordinate system $R_3=\{O_3X_3Y_3Z_3\}$ is the coordinate system of the object 3;
- Coordinate system $R_4=\{O_4X_4Y_4Z_4\}$ is the coordinate system of the object 4;
- Coordinate system $R_5=\{O_5X_5Y_5Z_5\}$ is the coordinate system of the object 5.

2.4. The independently generalized coordinates

From the assumptions and layout of objects, the BM-21 multiple launch rocket system has 6 independently generalized coordinates: $[q_j]=[\ q_1, q_2, q_3, q_4, q_5, q_6]$.

3. ESTABLISHING THE SYSTEM OF EQUATIONS OF VIBRATION OF THE LAUNCHER ON THE COMBAT VEHICLE

3.1. Vectors determine the coordinates of an object according to the generalized coordinates

- The vector $\overrightarrow{R_{O_i}} = \overrightarrow{O_0O_i}$ is a vector defining coordinates O_i point in the system of Coordinate O_0; $\overrightarrow{u_P} = \overrightarrow{O_iP}$ is a vector defining coordinates P point in the system of Coordinate O_i; A_j^i is the converts matrix the coordinates from the R_i coordinate system to the R_j coordinate system.

- The vector determines the point coordinates P in the original coordinate system:

$$r_P^{(0)} = R_{O_i}^{(0)} + A_0^i.u_P^{(i)} \tag{1}$$

- The angular velocity vector of i body in the O_0 coordinate system is determined as follows [1]:

$$\tilde{\varpi}_i = \dot{A}_0^i.A_0^i \tag{2}$$

3.2. Determine the kinetic energy of solid bodies

The ith solid object in the system is selected for the survey. The kinetic energy of an object is determined by the following formula:

$$T^i = \frac{1}{2}\left(\dot{R}_i^T.m_i.\dot{R}_i + \varpi_i^T.A_0^i.I_i.A_0^{iT}.\varpi_i\right) \tag{3}$$

3.3. Establishing a system of differential equations that describe the vibration of a launcher

Establishing the system of differential equations of the mechanical system using

Lagrange type 2 are written in the form of matrix [4] as follows:

$$\frac{d}{dt}\left(\frac{\partial T^{\Sigma}}{\partial \dot{q}_j}\right)-\frac{\partial T^{\Sigma}}{\partial q_j}=Q_j \tag{4}$$

Where: T^{Σ} - Total kinetic energy of the whole mechanical system; q_j – Independent generalized coordinate; Q_j - Generalized force corresponding to the generalized coordinates q_j.

4. APPLY, SOLVE THE SYSTEM OF DIFFERENTIAL EQUATIONS DESCRIBING THE VIBRATION OF A LAUNCHER BM-14

4.1. The forces acting on the mechanical system model BM-14

Based on the analysis of the structure of the BM14 combat vehicle and the established model, the mechanical system is affected by the following main forces:

a. The gravity of solid objects:

Gravitational force P_{ig} acting on the object is located at the center of mass of objects. In the fixed coordinate system, the gravitational force of the ith body:

$$P_{ig}^{(0)}=\begin{bmatrix}0 & 0 & -m_i.g\end{bmatrix}^T \tag{4}$$

b. The elastic forces of the elastic - viscous elements

The elastic potential of elastic elements is determined by the following formula:

$$\Pi_{S_i}=\frac{1}{2}\delta l_i^T.K_i.\delta l_i \tag{5}$$

Where: K_i is a matrix of hardness coefficient of the elastic element, $\delta l_i = l_i(t)-l_i(0)$. The displacement of the setpoint of elastic force compared to the initial state.

c. The firing force

The firing force is the force that the firing rocket acting on the launcher. The firing force is the main component causing the vibration of the launcher. The firing force is generated by many complex force components such as: The braking stage, the gravity of the rocket, the force caused by exhaust gas flow, the force is generated by the rotation of the rocket in the launcher, etc.

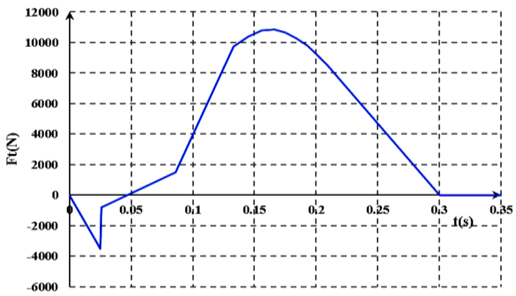

Figure 2. *Stage of exhaust gas acting on the launcher and firing sequence.*

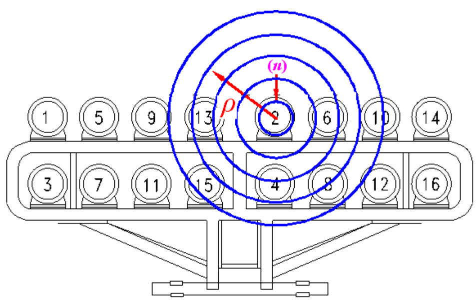

Figure 3. *The shape of the firing force F_t.*

These force components have a relatively complex direction and sensitive direction in space. However, it acts on the launcher mainly along the axis of the launcher. Therefore, the axial force component of the launcher tube is considered to be the firing force. The firing force consists of 3 stages: The braking stage, the orientation stage, and the exhaust gas stage. The firing force graph is shown in figure 2.

4.2. Calculation results

With the firing order arranged as shown in figure 3, the d-solve command in Maple software is used to solve the system of differential equations describing the vibration of the launcher on a BM14 combat vehicle.

To investigate the influence of using hydraulic jacks on BM-14 battle vehicles, the vibration of BM-14 launchers was investigated in the following cases:

- Case 1: Using hydraulic jacks, the ground is considered to be inelastic;
- Case 2: Using hydraulic jacks, the ground is considered to be elastic;
- Case 3: Without using hydraulic jacks, the ground is considered to be elastic.

The results of oscillation of the launcher when single and multiple firing are shown in figure 4 and figure 5:

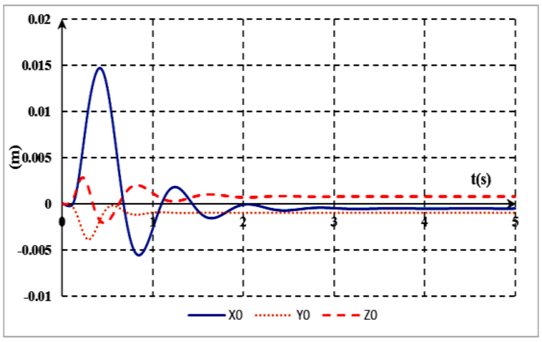

Figure 4. *Vibration of a launcher when single firing.*

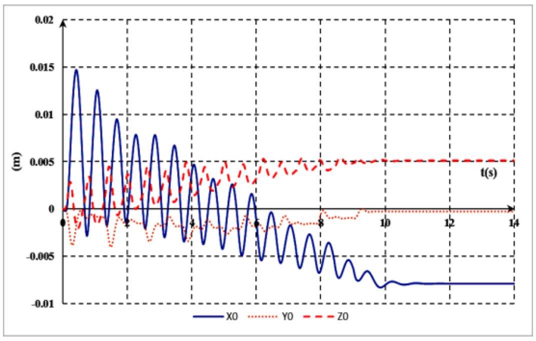

Figure 5. *Vibration of the launcher when series firing.*

- When fired, the mechanical system is affected by the loads, so the launcher oscillates around the equilibrium position. From Figure 5 shows that the oscillation in the $\overrightarrow{X_0}$ direction is the largest, this oscillation is the main cause of the launching angle deviations.

- When single-fired, the vibration time of the mechanical system is 2.5 seconds. After that, the system returned to its equilibrium position but not the original position because at this time the mass and the center of mass of the unfired bullets had changed. Therefore, the launching angle of the next shot will be different from the original firing.

- When series fired, the system deviates from its equilibrium position and oscillates around the new position, when the firing is stopped, the system returns to the new equilibrium position, this position has a greater deviation than the first firing. This deviation directly affects the accuracy of the next firing.

The oscillation graph of the launcher when surveyed for the three cases is plotted on the same graph as figure 7, figure 8, and figure 9.

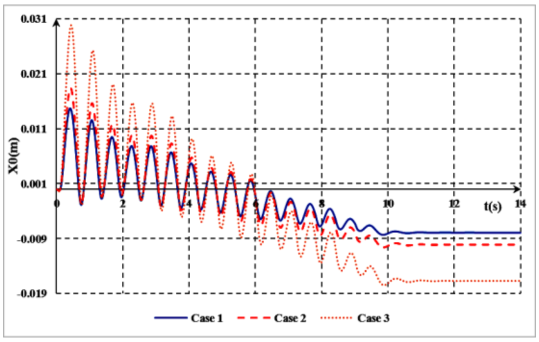

Figure 6. *Vibration of the launcher in* $\overrightarrow{X_0}$.

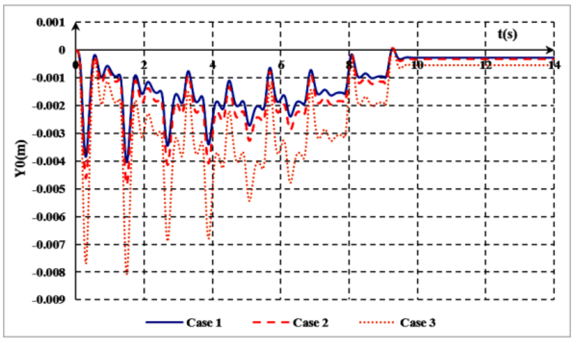

Figure 7. *Vibration of the launcher in* $\overrightarrow{Y_0}$.

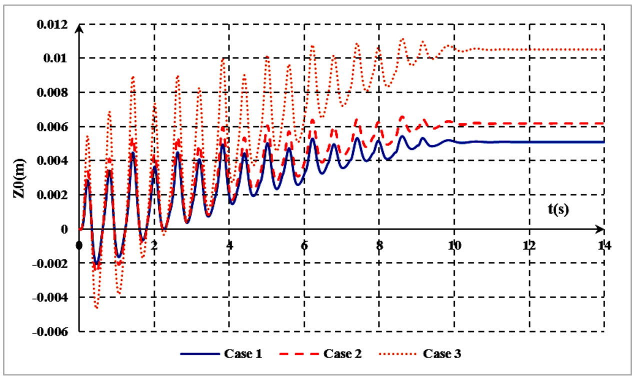

Figure 8. *Vibration of the launcher in* $\overrightarrow{Z_0}$ *direction.*

- When the mechanical system is fired in unused hydraulic jacks mode and the ground is elastic, the amplitude of vibration of the launcher is greatest. In this case, 2 rear tires and 2 rear tweezers are released, the mechanical system is affected by many elastic elements.

- The survey results in figure 7, figure 8, and figure 9 also show that the new equilibrium position corresponds to the survey case 1, case 2, and case 3 further and further away from the original equilibrium position.

- When studying the vibration of the launcher, investigation of the factors affecting the vibration of the launcher is an important basis for accurately determining the input parameters for the transfer of rocket in space.

5. CONCLUSIONS

The paper has built the BM-14 combat vehicle mechanical model based on the multi-material merchanics theory. The mechanical model, coordinate system and generalized coordinates were chosen as general quantities, used to survey launcher in single and series fired. The algorithm scheme and solution method are applied to set up for all the launchers on rubber tire vehicles using hydraulic jacks when firing.

The result of the paper is the analysis and evaluation of the effects of the firing on the stability of the launcher when fired. Since then, the reliability of combat vehicles using hydraulic jacks has been specifically evaluated.

Acknowledgement: *The authors thanks for the support of the Military Institute of Science and Technology in the study and published the results of this paper.*

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TÓM TẮT

MÔ HÌNH TÍNH TOÁN ĐỘNG LỰC HỌC GIÀN PHÓNG TRÊN XE CHIẾN ĐẤU CÓ SỬ DỤNG KÍCH ĐẶT TRÊN NỀN ĐÀN HỒI

Trong bài báo, mô hình động lực học dàn phóng xe chiến đấu có sử dụng kích được thiết lập. Cơ sở lý thuyết về cơ học hệ nhiều vật được sử dụng để thiết lập phương trình toán học mô tả dao động của dàn phóng khi phóng. Nền đất trong mô hình khảo sát được coi như là một phần tử đàn hồi có độ cứng K và hệ số cản nhớt C. Kết quả nghiên cứu được áp dụng để tính toán cho xe chiến đấu BM14, độ ổn định của dàn phóng BM14 khi phóng đơn và phóng loạt được khảo sát cụ thể trong các trường hợp: Có sử dụng kích và nền đất được coi là không đàn hồi; Có sử dụng kích và nền đất được coi là đàn hồi; Không sử dụng kích và nền đất được coi là đàn hồi. Kết quả khảo sát cho thấy mức độ tin cậy của giàn phóng khi bắn. Nội dung bài báo là cơ sở lý thuyết đóng góp trong quá trình cải tiến, thiết kế, chế tạo và khai thác sử dụng các loại xe chiến đấu có sử dụng kích đạt hiệu quả cao.

Từ khóa: Kích thủy lực; Giàn phóng bắn loạt BM-14; Dao động của dàn phóng.

Received 1st November 2020
Revised 3rd December 2020
Accepted 10th May 2021

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