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Defining the Elasticity Elimination Mechanism of Multiple Rocket Launcher Vehicle

This paper presents the parameters that are important for defining the mechanism for elasticity elimination in the launching device vehicle. The basic dynamic analysis of rocket launcher is presented, which is of crucial importance for discovering the influential parameters necessary for calculating the required power for mechanism for elimination vehicle's elasticity. The paper also presents the calculating of the required power for the device for the vehicle's elasticity elimination, which is composed of reduction gear, thread transmission, and so called linear actuator. The transmission ratios, moments and mechanism's required power for both motor and manual drive are given, too. The paper considers various types of soil supporting the combat vehicle and their impact on the mechanism of vehicle's elasticity elimination.

Keywords: *mechanical model, reduction gear, launching device, actuator, device for vehicle's elasticity elimination, legs.*

1. INTRODUCTION

The main reason for installing the device for elastic system elimination is the need to provide both the static and dynamic stability of rocket launcher during launching as well as to eliminate the elastic system (springs and tires), Fig. 1. The paper will consider the problem related to self-propelled multitube rocket launchers (MLRS).

Figure 1. MLRS with a device for the vehicle elastic system

A load at support in dynamic mode is in correlation with the stability. To determine the shape and the size of supporting elements (relief at the legs, besides the stabilizing role, has another important role: to switch off the system elasticity – springs and tires) we have to study the size and nature of the load that affects rocket launcher elements. In this paper, a general "structural" model that could be applied to any self-propelled multitube launcher will be established. Using the mechanical model, a mathematical model is established on the basis of which all required parameters necessary for the calculation of mechanisms for elasticity elimination [1,2] are determined.

2. MECHANICAL MODEL

The basic fact for the definition of the dynamic model, rocket – multiple launcher rocket system (MLRS), is that the launcher is doing free-damped oscillations after the moment when the rocket leaves the launching tube. Initial conditions of this oscillation are determined by the disturbances that occurred during the rocket's start.

The most important disturbances, after they are created during the rocket's start, are: action of the rocket's lock, motion of the rocket along a launching tube and action of the exhausted from rocket motor on MLRS. The general mechanical model is set considering the analysis exposed in [1,3]. This model is composed of the stiff bodies with concentrated masses and flexible elements and elastic dampers (Fig. 2). In this paper, it will be studied reinforced frame of the vehicle with four stiffly connected legs. The function of the four legs is to eliminate the elasticity of the bottom-structure of the vehicle. The legs differ in design, mode of connection driving-gear and mode of automatic control. From the point of view of the mechanical model, the legs are classified by type of the support - point contour: two, three or four supports. For all three types of support-point contour, it is characteristic the symmetry, related longitudinal axis, in view of geometry and support stiffness.

In this mechanical model, the stiffness of the support comprises this of the ground and that of the legs. In a concrete case, the legs have incomparable bigger

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stiffness than a ground. And for this reason, adaptation has been made so that the stiffness of the ground represents stiffness of the whole support. Mechanical characteristics of the ground are presented in [1].

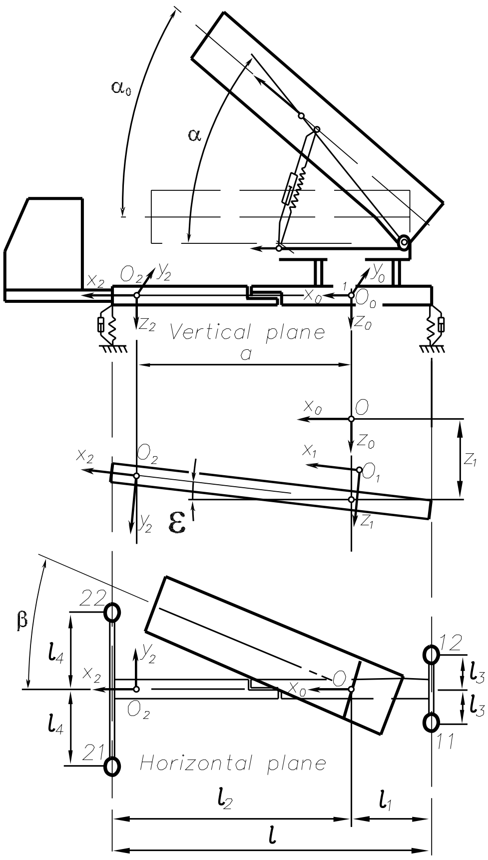

Figure 2. MLRS mechanical model

In this paper, we used basic foundations of the mechanical model of reinforced frame model by Volkov and Timin presented in detail in [4]. A model of the reinforced frame of the vehicle is presented in Figure 3.

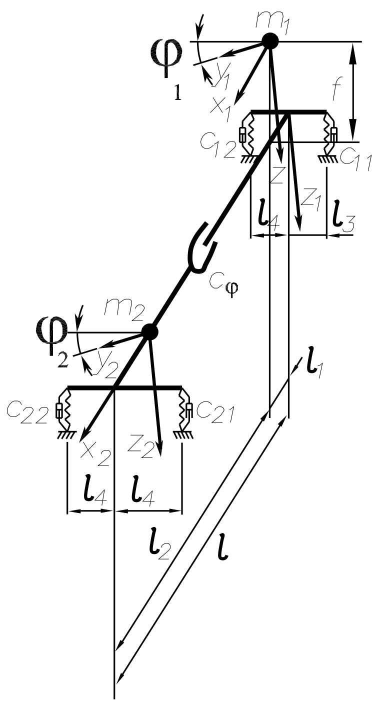

Figure 3. Mechanical model of MLRS vehicle reinforced frame

A part of the overhanged supporting frame of the azimuth mechanism represents a console, elastic onto flexion, of stiffness characteristic. Other parts of the azimuth mechanism can be assumed to be a stiff body. Elevation mechanism (lifters) and leveling mechanism (longitudinal and transversal lifters) are represented by the batons connected in series and modeled as a spring, of reduced stiffness on extension and compression together with hydraulic damper (Fig. 2).

In the process of launching there occurs the deformation of the launching tube as a result of the loading on flexion. This problem can be resolved with high accuracy by approximating the launching tube by the beam with overhang. This beam is supported in the front and rear plates.

The rest of the launching device, as a launching box with tube's (loaded or empty) represents a stiff body. According to the above mentioned model, the motion (oscillation) of MLRS, during the launching process, is defined by the next generalized coordinates:

- z_1 – vertical motion of the Vehicle' frame (at direction of 2 axis) along the 2 axis;
- ε – rotation of the vehicle's frame round the transversal y axis;
- φ_1 – twist of the rear part of the vehicle's frame round a longitudinal axis;
- φ_2 – twist of the front part of the vehicle's frame round a longitudinal axis;
- ψ – inclination of the lower frame's console of the azimuth mechanism;
- θ – rotation angle of the launching device rant rotate point of elevation O_3;
- ψ_1 – inclination of the tube top.

For the analysis of oscillating, motion, it is convenient to use the equations of Lagrange which have the next shape:

$$\frac{\mathrm{d}}{\mathrm{d}t}\left(\frac{\partial E_{\mathrm{k}}}{\partial \dot{q}_r}\right)-\frac{\partial E_{\mathrm{k}}}{\partial \dot{q}_r}+\frac{\partial E_{\mathrm{p}}}{\partial q_r}=Q_r^n \tag{1}$$

where E_{k} is kinetic energy, E_{p} is potential energy, Q_r^n is generalized unconservative forces (disturbances and damping forces), q_r is generalized coordinates, $\dot{q}_r$ is generalized speed's and r = 1,2,3,…,s is number of degrees of freedom.

3. MECHANISM FOR SYSTEM'S ELATICITY ELIMINATION IN FUNCTION OF DYNAMIC AND STATIC STABILITY

The first study that considered the dynamic free stability of structure relied on the ground, is probably that by Malchukov's [2]. The author set two conditions that will be shown.

a) Angle of machine's rotating must not exceed the limits when the moment of stability becomes a moment rummage

$$\varphi_{\mathrm{gr}}=\mathrm{arctg}\left(\frac{x_0}{y_0}\right), \tag{2}$$

where x_0 and y_0 are the coordinates of the center of mass in the mobile coordinate system.

b) Constant contact between support and surface

$$F_i(t) > 0\,, \tag{3}$$

where $F_i(t)$ is a normal component of the reaction at support i.

According to Figure 2 the load at support in dynamic mode can be presented as

$$F_{jk} = c_{jk}\Delta l_{jk} = c_{jk}(\lambda_{jk} + f_{jk} + \phi\dot{f}_{jk}) \tag{4}$$

where Δl_{jk} is the total deformation, f_{jk} is dynamic deformation of support and surface, $\dot{f}_{jk}$ is support deformation velocity, ϕ is module of surface damp, λ_{jk} is static deformation at support and c_{jk} is rigidity of support (surface).

Deformation f_{jk} will be presented in a linear form assuming that there is only vertical displacement, i.e.

$$\begin{aligned} f_{11} &= z_1 + l_1\varepsilon - l_3\varphi_1\,, \\ f_{12} &= z_1 + l_1\varepsilon + l_3\varphi_1\,, \\ f_{21} &= z_1 - l_2\varepsilon - l_4\varphi_2\,, \\ f_{22} &= z_1 - l_2\varepsilon + l_4\varphi_2\,, \end{aligned} \tag{5}$$

and appropriate velocity of deformation

$$\begin{aligned} \dot{f}_{11} &= \dot{z}_1 + l_1\dot{\varepsilon} - l_3\dot{\varphi}_1\,, \\ \dot{f}_{12} &= \dot{z}_1 + l_1\dot{\varepsilon} + l_3\dot{\varphi}_1\,, \\ \dot{f}_{21} &= \dot{z}_1 - l_2\dot{\varepsilon} - l_4\dot{\varphi}_2\,, \\ \dot{f}_{22} &= \dot{z}_1 - l_2\dot{\varepsilon} + l_4\dot{\varphi}_2\,. \end{aligned} \tag{6}$$

Conditions listed under a) and b) are reduced to one if the rigidity of surface is relatively high, i.e.

$$F_i(t) > 0\,. \tag{7}$$

When the reaction at one of the rocket launcher's supports equals zero, we can talk of conditional instability. Unconditional instability occurs when reactions of at least two supports are equal to zero.

Since the attenuation coefficient of soil is a relatively small value, (4) becomes sufficiently accurate:

$$F_{jk} = c_{jk}(\lambda_{jk} + f_{jk})\,. \tag{8}$$

Since the boundary angle at a relatively high surface rigidity could be achieved only after breaking the contact between the support and the surface, the two conditions under a) and b) are reduced to only one:

$$F_{jk} = c_{jk}(\lambda_{jk} + f_{jk}) > 0 \tag{9}$$

and movement

$$\lambda_{jk} > -f_{jk}\,. \tag{10}$$

The equation (10) defines the condition of SMRL stability.

4. A FORCE REQUIRED FOR ELASTIC SYSTEM RELIEVING

From (9) we shall infer the conclusion about the value of static deformation on supports, and the force required for static relieving of elastic system (springs and tires) for each support.

$$F_{\mathrm{st}\,jk} = \lambda_{jk}c_{jk} \tag{11}$$

where $F_{\mathrm{st}jk}$ is static relief per support.

The total relief for the whole system will be:

$$F_{\mathrm{u}} = \sum_{j}^{n}\sum_{k}^{n}\lambda_{jk}c_{jk}\,. \tag{12}$$

5. A SAMPLE OF THE CALCULATION OF THE POWER REQUIRED TO SET IN MOTION THE DEVICE FOR SYSTEM'S ELASTICITY ELIMINATION

5.1 Automatic motor drive

Figure 4 shows a kinematic scheme of an already implemented design that consists of worm transmission 1, power screw transmission with recirculation nut with pellets 2 and jaw coupling 5. A power screw transmission spindle is connected with a piston rod mounted on nut 3 that has a role of linear actuator with the supporting plane (supporting plate) on joint at its end. The role of jaw coupling is to disconnect a worm transmission during the manual operating and thus enable fast lowering of the piston rod with the supporting plate 6. Cylinder 4 is connected to the vehicle chassis by a rigid carrier.

Figure 5 shows the above described design.

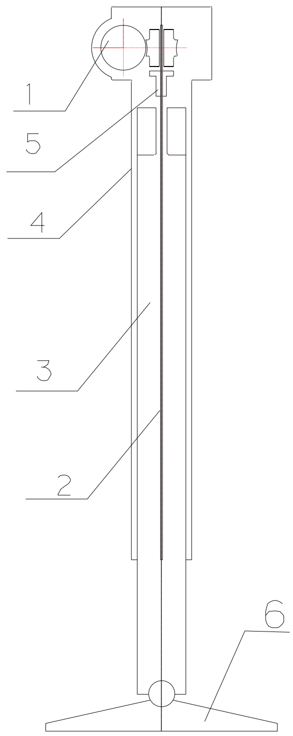

Figure 4. Leg kinematics diagram

This paper will present the basic calculation of the required power per supporting unit using the example of SMRL given in [1].

Figure 6 is a diagram of the back left leg (support) dynamic deformation f_{jk} from the example given in [1] that is one of the differential equations solutions (1).

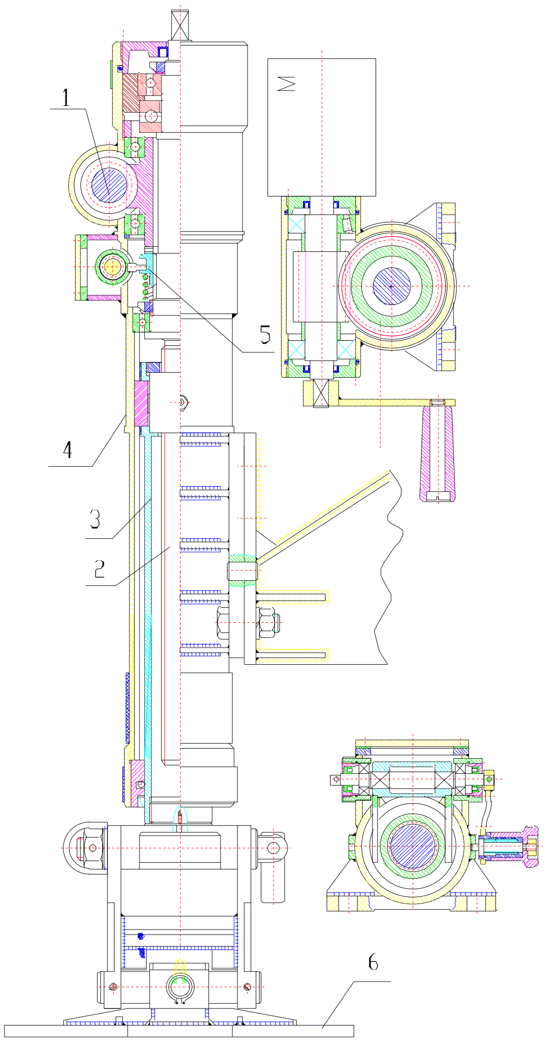

Figure 5. Leg design

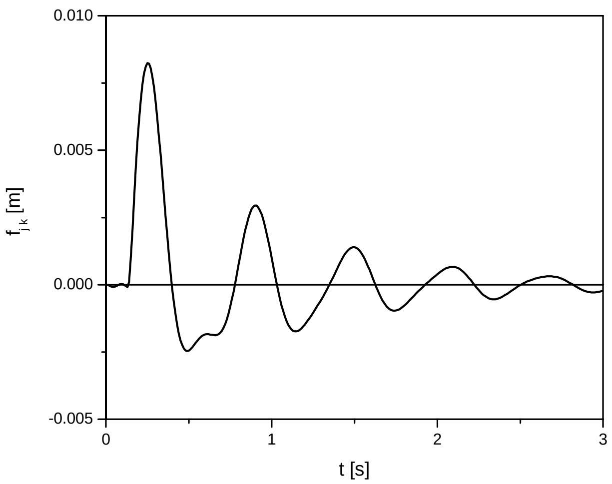

Figure 6. Movement of the rear left leg

According to (11), the static force of relieving F_{st} = 12,000 N, for further calculation we will adopt:

$$F = F_{st} = 1500 \text{ N}. \tag{13}$$

The selected spindle with recirculation nut has the following basic characteristics:

- d_n = 32 mm, nominal diameter;
- h = 10 mm, pitch of thread;
- c_o = 50,000 N, static carrying capacity;
- c = 33,000 N, dynamic carrying capacity.

The selected worm gear has the following basic kinematic characteristics:

- q = 10, worm number;
- z_1 = 1, number of worm's threads;
- z_2 = 20, number of worm gear's teeth;
- $i_1 = z_2/z_1$ = 20, transmission ratio;
- γ_m = 5.71°, helix angle of worm's thread.

Moment M_i of the screw spindle required to obtain relief force F

$$M_i = F\frac{1}{2}d_2 \operatorname{tg}(\varphi+\rho) = 28 \text{ Nm}. \tag{14}$$

where d_2 is mean thread diameter, φ = 6.05° is helix angle of spindle thread is known from the kinematic relation, μ_v = 0.015 is thread friction in a factor in the bolted connection, $\rho = \operatorname{arctg}\mu_v$ = 0.85° is angle of friction and $\varphi \succ \rho$ is condition for bolted pair being self-locking.

Transmission ratio of a reductor

$$i = \frac{M_i}{M_u \eta} \tag{15}$$

where $M_u = M_i/\eta i = 5.6$ Nm, is motor driving moment, $\eta_p = \operatorname{tg}\gamma_m / \operatorname{tg}(\gamma_m + \rho_p) = 0.26$ is efficiency worm transmission, μ_p = 0.25 is friction factor in the worm gear (steel/bronze), $\rho_p = \operatorname{arctg}\mu_p = \operatorname{arctg} 0.25$ = 15°, $\eta_l = \eta^4 = 0.99^4$ is total efficiency of bearings and $\eta = \eta_l\,\eta_p$ = 0.25 is efficiency.

Total efficiency:

$$\eta_u = \eta_l \cdot \eta_p \cdot \eta_v = 0.96 \cdot 0.25 \cdot 0.85 = 0.24\,. \tag{16}$$

An important factor in the rocket system exploitation is it's preparing time, and it includes a short operating period of time of the linear actuator. The maximum allowed operating time for the actuator drawing is t = 30 s, and the rod piston's designed drawing length to achieve the required relief force is L = 400 mm.

From well-known kinematic relations we will achieve the necessary number of revolutions for the motor and it is n = 26.6 rps, and angular velocity is $\omega = 2\pi n$ [rad/s].

A required driving power for the motor is:

$$P = M\omega = 935 \text{ W}. \tag{17}$$

It can be concluded that the efficiency is quite low, mostly due to worm gear. The worm gear provides self-locking, which is the major feature of these mechanisms. This means that the self-activating motion of liner actuator will not occur with pretty high degree of reliability. If it is not self-locking, it would lead to unwanted results for the specific use of such systems.

As the most influential factor for calculating the required drive power of the motor stands out the stiffness of supports; in this case the soil stiffness c and efficiency of supporting leg mechanisms.

5.2 Manual operation

For ergonomic reasons the manual operation force of the arm must not be exceeded, F_r = 100 N, which at the handles arm of r = 0.1 m gives the moment of the manual operation:

$$M = F_r r = 10 \text{ Nm}. \qquad (18)$$

The required moment at the shaft of the driving motor ensures that the hand-operating by the handles can be done on the same shaft without a need for new reduction.

6. SUPPORTING CONTOUR AND DIMENSIONS OF SUPPORTING PLANES

6.1 Supporting contour

Supporting contour considers a polygon, whose vertices are supporting legs. The most common disposition of a supporting contour includes four supports (legs) arranged symmetrically in relation to the longitudinal SMRL and stiffly fastened to the vehicle chassis. One of the main conditions that have to be met in this case is that the center of gravity of the upgrading load during its motion by azimuth and elevation must not exceed the quadrilateral supporting contour.

6.2 Dimensions of support plane

The surface of support plane (support plate) must provide that the pressure level will not exceed a specific limit of soil pressure.

$$p_{\mathrm{g}} \geq p_{\mathrm{sp}} \qquad (19)$$

where p_{g} is specific soil pressure and p_{sp} is support plane pressure (support plane).

Table 1 gives the values of specific pressure for certain types of soil from which the launching is to be done.

Table 1. Values of specific pressure

Type of soil	Allowed specific pressure [bar]
Compressed soil	
Hard clay, hard rocky soil	6
Moderatly hard clay	4
Soft clay	1
Loose soil	
Compact gravel, compact mixture of gravel and sand	1
Loose gravel	0.8
Loose sand	0.6
Fine sand	0.2

7. CONCLUSION

The power required to relieve the SMRL in the process of rocket launching depends on the dynamic characteristics, type of support soil and efficiency of mechanisms of actuators.

The design solution of supports shown in this study is quite bad from the viewpoint of the engaged power, because these systems are generally limited to energy resources. However, the proposed solution has a high degree of reliability in respect of its main function of relief, because it is self-locking.

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ДЕФИНИСАЊЕ МЕХАНИЗМА ЗА ЕЛИМИНАЦИЈУ ЕЛАСТИЧНОСТИ ВОЗИЛА ВИШЕЦЕВНИХ БАЦАЧА РАКЕТА

Драгослав Живанић, Милан Милошевић, Мирослав Пајчин, Угљеша Бугарић, Душан Петровић, Зоран Петровић

У раду су приказани параметри који су од важности за дефинисање механизма за искључење еластичности возила код лансирних уређаја. Приказана је основна динамичка анализа лансера која је од круцијалног значаја за изналажење утицајних параметара за прорачун потребне снаге. Дат је приказ прорачуна механизма за искључење еластичности возила, који је састављен од редуктора, навојног преносника и тзв. линеарног актуатора. Дати су преносни односи, моменти и потребна снага моторног и ручног погона механизма. Дати су типови подлоге на које се врши ослањање борбеног возила и њихов утицај на механизам за искључење еластичности возила.