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Synthesis Impact Protection Implemented in a Particular Facility Through Friction Dampers

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***Abstract*— In the present study, a dedicated damper has been developed to significantly reduce the substantial recoil generated by the detonation of the mortar's main charge. This enables the gunner of the artillery system to perform instrument calibration checks less frequently, which in turn contributes to more efficient mortar fire control.**

***Keywords*— computer kinematical analyses, four-bar linkage mechanism, Math Lab.**

I. Introduction

In my capacity as a lecturer supervising a group of students employed at ARMACO INDUSTRIES AD, I developed the damper illustrated in Fig. 1. The device was designed for an 82 mm battalion mortar and contributes to reducing the recoil force and, consequently, the reaction acting on the aiming instruments of the artillery system. Following successful experimental validation, I submitted the relevant documentation to the Bulgarian Patent Office. The patent clearance procedure is expected to continue until the end of 2026.[1], [2], [3], [4], [5], [6], [7], [8].

The effectiveness of the damper is primarily attributed to the arrangement and geometry of the channels within cylinder 3 shown in Fig. 1. As baseline technical references, sources related to machine mechanics were utilized:[9], [10], [11], [12], [13], [14], [15], [16].

The mechanical system to which the investigated object is reduced is a single-mass system with one degree of freedom, as illustrated in Fig. 1. The figure shows that the mass of the device **m** is suspended by an elastic element with spring constant **c** and a friction damper with Coulomb force **T**, both operating in an environment subjected to single or cyclically repeated impact loads. [17], [18], [19], [20], [21], [22], [23].

The function of the damper shown is to extinguish the significant recoil during successive fire from the artillery installation, minimizing the correction of the measuring instruments.

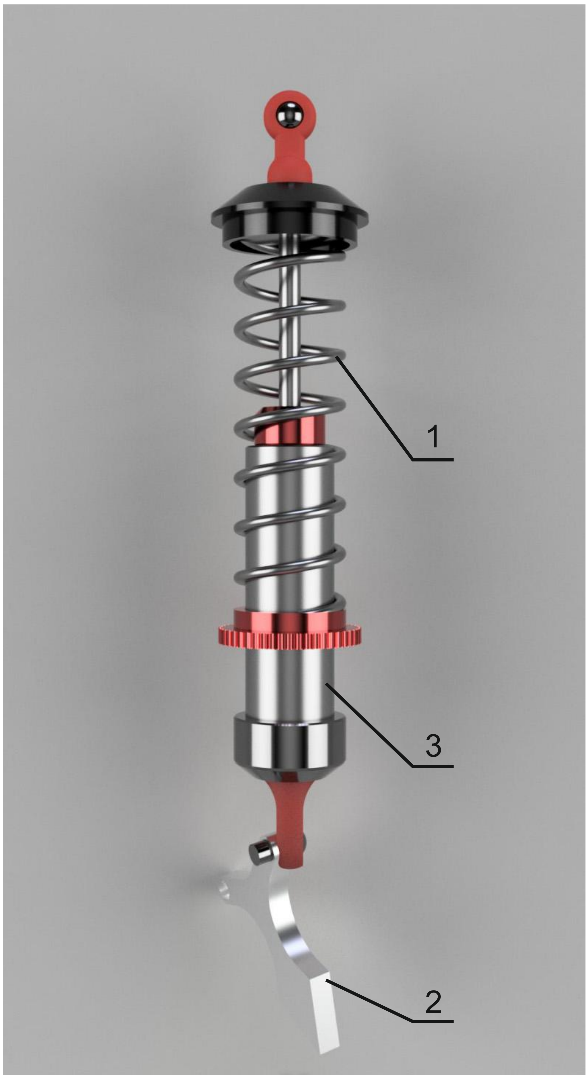

Fig.1 Friction damper

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When solvingthe problem, a unified approach to the synthesis of planar guiding or transmission mechanisms, presented by Marinov [8], was used.

Figure 1 illustrates a mechanical shock-protection system for a mechanism with mass ***m.*** Element 1 denotes a spring with spring constant ***c,*** element 2 represents the mechanism with mass ***m*** and element 3 denotes a friction damper with friction force ***T***.

II. Materials and Methods

It is well known from mechanics that in case of impulse impacts, the generalized mass of the model with initial velocity V_0 and lack of damping is carried out according to the law:

$$x = \frac{v_0}{k}.\sin(k.t) = C_2.\sin(k.t)(1) ,$$

Where $k = \sqrt{\frac{c}{m}}$ is the natural frequency of the mechanical system .

When the friction damper is connected to the machine unit, the movement of the mass from the zero position to the maximum deviation in the direction of impact will be carried out according to the law:

$$x = C_1.[cos(k.t) - 1] + C_2.\sin(k.t)(2) ,$$

Where $C_1 = \frac{T}{c}$, $C_2 = \frac{v_0}{k}$.

The largest amplitude along the x axis that will be realized as a result of the impact will be:

$$x_1 = C_1.\left[cos\ arctg\left(\frac{C_2}{C_1}\right) - 1\right] + C_2.\sin arctg\left(\frac{C_2}{C_1}\right)(3)$$

If known trigonometric relationships are used, equation (3) can be represented as:

$$x_1 = \sqrt{C_1^2 + C_2^2} - C_1 \quad . \quad (4) .$$

The time from the moment the impact is applied to the moment the amplitude of the mass in the direction of impact reaches x_1 will be:

$$t_1 = \frac{1}{k}.arctg\frac{C_2}{C_1}(5)$$

After the mass of the device reaches the maximum deflection x_1 in the direction of impact, its motion changes direction, and from that moment until the moment when it reaches the maximum deflection in the direction opposite to the impact, the equation of motion will have the form:

$$x = D_1.\cos(k.t) + D_2.\sin(k.t) + C_1(6) ,$$

Where $D_1 = \frac{C_1(x_1 - C_1)}{\sqrt{C_1^2 + C_2^2}}$, $D_2 = \frac{C_2(x_1 - C_1)}{\sqrt{C_1^2 + C_2^2}}$.

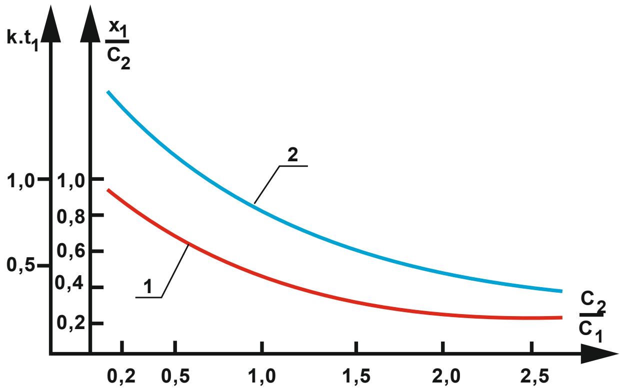

Fig.2

Fig. 2 shows a graph of the change in the amplitude x_1, depending on the change in the amplitude of the free oscillations C_2 of the system and the time t_1, depending on the natural frequency k, at different deviations $\frac{C_2}{C_1}$.

The largest deflection that the mass of the device will make in the direction opposite to the direction of impact will be:

$$x_2 = -x_1 + 2.C_1 \qquad (7) ,$$

The time from the moment the impact is applied to the moment the deflection of the mass of the device in the direction opposite to the impact reaches x_2 can be determined from the equation:

$$t_2 = \frac{1}{k}\left(arctg\frac{C_2}{C_1} + \pi\right) \qquad (8) ,$$

The motion of the mass, from the moment t_2, to the next maximum deflection in the direction of impact, can be expressed by the equation:

$$x_1 = E_1.\cos(k.t) + E_2.\sin(k.t) - C_1 \qquad (9) ,$$

Where $E_1 = -\frac{C_1(x_1 - 3.C_1)}{\sqrt{C_1^2 + C_2^2}}$, $E_2 = -\frac{C_2(x_1 - 3.C_1)}{\sqrt{C_1^2 + C_2^2}}$

The second maximum mass deflection, in the direction of impact, will be:

$$x_3 = x_1 - 4.C_1 \qquad (10) .$$

From expressions (2), (4), (6), (7), (9) and (2.10) it is seen that the mass of the device after the impact performs a damped mechanical oscillation. The change in amplitude for one period is $\Delta x = \mp 4.C_1$. The oscillations of the system will continue until the next deviation is between the points with coordinates $x = \pm C_1$. In this zone the elastic force is less than the friction force **T**.

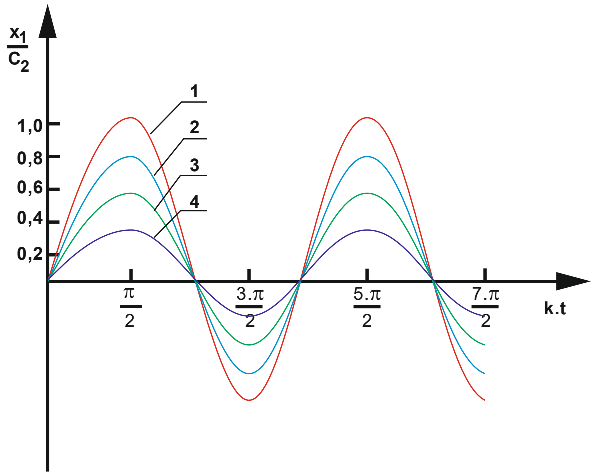

Fig.3 shows the motion of a mass subjected to a single impact at different ratios $\frac{C_2}{C_1}$.

The change in velocity and acceleration of the object's mass, for the period from the beginning of the impact until the moment it reaches the largest deviation x_1 in the direction of impact, follow from expression (2), namely:

$$\dot{x} = -C_1.k.\sin(k.t) + C_2.k.\cos(k.t) \quad (11),$$

$$\ddot{x} = -C_1.k^2.\cos(k.t) + C_2.k.\sin(k.t) \quad (12),$$

and their maximum values will be:

$$\max\dot{x} = k.\sqrt{C_1^2 + C_2^2} \quad (13),$$

$$\max\ddot{x} = -k^2.\sqrt{C_1^2 + C_2^2} \quad (14).$$

When synthesizing shock protection for a device or other object, using a mechanical system of an elastic element (spring) and a friction damper from the GERWAH company, it is necessary to clarify in advance what are the permissible kinematic characteristics (mass deviation, as well as permissible linear and angular velocities and accelerations) at which the object of protection will operate reliably, i.e. it will not give a series of failures or the strength of the units and the kinematic connections between them will not be impaired.

III. Results and Discussions

The mortar is a type of artillery weapon intended for high-angle fire against concealed targets, as well as for the destruction of field fortifications.

The main combat qualities of the mortar are: the high power of the ammunition (mines), the high rate of fire, the relatively low mass, the elementary arrangement of the mechanisms during combat use, the constant readiness to open fire, without special training of the service crew.

A characteristic feature of the mortar is: the large trajectory of the mines' flight (the firing angle allows a change from 45° to 85°) allows the destruction of concealed targets, indestructible by automatic and artillery fire.

Fig.4 shows a photo of an American field mortar M224. A characteristic feature of this type of artillery installation is the lack of any kind of damping, due to the fact that the barrel of the gun, in its lower part, is based on the so-called a plate whose purpose is to distribute the impact of the mine detonation, transmitting it to the surface of the earth, possibly over a larger area. With each shot, the optical measuring device loses the main direction of the shot, if there is no special anti-shock protection.

This publication proposes a methodology for calculating the anti-shock protection of the measuring device, using a helical cylindrical spring and a friction damper.

Fig.4 Mortar with application of the developed damper.

The spring is made of 4X13 spring steel with a cross section of Ø5mm, number of coils n=8 and length L=120mm. The friction damper is made of a stem made of 40X steel and contacting along its length with a rubber filler.

IV. Conclusion

The present publication proposes a model of a single-mass anti-shock mechanism that can successfully protect the measuring instrument of any small-caliber artillery installation, such as the American model 60 mm M224, and the Russian model 82 mm battalion mortar MX82. The orientation of the anti-shock protection shown in Fig. 1 should be in a direction parallel to the body of the mortar, in order for the protection to be maximally effective, i.e.: after each detonated mine, the impact that is directed towards the plate based on the ground and the residual vibrations that cannot be absorbed by the plate, should be absorbed for one cycle by the friction damper and the spring.

In artillery installations with a large caliber, for example 120 mm or larger, this type of impact protection is ineffective and hydraulic or gas vibration dampers are used. They are mounted parallel to the body of the mortar, with the dampers usually being two, placed 180° around the barrel of the artillery unit. In self-propelled artillery units, hydraulic dampers are mandatory, which are extremely effective in preserving the integrity of the chassis of the self-propelled unit. Such a damper is mounted on the Bulgarian self-propelled mortars 2S9 "Tundzha" 120mm, manufactured in 1986-1987. which are currently in service with the Bulgarian Army.

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REFERENCES

[1] I. Artobolevskiy, Theory of Mechanisms and Machines. Science, Moscow, 1967.

[2] V. Bhandari, Design of Machine Elements Fifth Edition, McGraw Hill 2020.

[3] V. Galabov, M. Marinov and N. Nikolov, Synthesison a guiding MF at two points, respectively phase relation and double midpoint, "Mechanics of machines" 1999, booklet 26.

[4] V. Galabov and M. Marinov, Synthesis of articulated four-link mechanism by discrete relative positions. "Mechanics of the machines",Varna, 2002.

[5] G. Iliev and H. Hristov, "Modelling and simulation ot electropneumatic positioning system including the length of pneumatic lines", ETR, vol. 3, pp. 106–111, Jan. 2024, doi: https://doi.org/10.17770/etr2023vol3.7186.

[6] G. Iliev and H. Hristov, Speed control pneumatic cylinders using high speed 2 port on/off valves with pulse width modulation. environment, technologies, resources. Proceedings of the International Scientific and Practical Conference. 3, (Jun. 2024), 95–100. DOI: https://doi.org/10.17770/etr2024vol3.8117.

[7] J. Uicker, G. Pennok and J. Shigley, Theory of Machines and Mechanisms, Fifth Edition, Oxford University Press 2017.

[8] M. Marinov, Synthesis of planar mechanisms by extremely distant discrete positions. Dissertation abstract to get thescientific and educational degree "PhD" - TU Sofia 2002, pp.36.

[9] D. Myszka, Machines & Mechanisms: Applied Kinematic Analysis, 2011.

[10] M. Marinov, B. Stoychev, D. Guteva and M.Georgiev, Computer modeling and geometricanalysis of Click-Clack mechanisms. "Mechanics ofthe machines" 2016 booklet 118 pp.35-39.

[11] M. Stanisic, Mechanisms and machines; Kinematics, Dinamics and synthesis, Stamford 2015.

[12] L. Harrisberger, An overview of structural synthesis of three-dimensional mechanisms, constructingscience and technology of mechanical engineering, World, Moscow, 1965.

[13] D. Petrova, B. Vlahova, A. Lengerov and T. Zlateva-Petkova, Improvement of Constructive-Technological Approaches Reducing Innovative Obsolescence of Industrial Technologies in the Context of Industry 4.0, Vide. Tehnologija. Resursi - Environment, Technology, Resources, Proceeding of the 14th International Scientific and Practical Conference, 2023, Volume I, pp. 180–186, Print ISSN 1691-5402, Online ISSN 2256-070X, DOI: https://doi.org/10.17770/etr2023vol1.7238 https://www.scopus.com/authid/detail.uri?authorId=56323816400

[14] D. Petrova, B. Vlahova, A. Lengerov and T. Zlateva-Petkova, Study of the State of Innovation Development and Obsolescence in the Republic of Bulgaria of Companies from the Mechanical Engineering Sector, Vide. Tehnologija. Resursi - Environment, Technology, Resources, Proceeding of the 14th International Scientific and Practical Conference 2023, Volume I, pp. 187–194, Print ISSN 1691-5402, Online ISSN 2256-070X, DOI: https://doi.org/10.17770/etr2023vol1.7239 https://www.scopus.com/authid/detail.uri?authorId=56323816400

[15] D. Petrova, N. Nikolova and A.. Lengerov, Modeling business process reengineering in the digital era of industry 4.0, 11th International Scientific Conference "TechSys 2022" – Engineering, Technologies and Systems, AIP Conf. Proc. 2980,070013-1–070013-7; https://doi.org/10.1063/5.0185275, Published by AIP Publishing. 978-0-7354-4814-8/$30.00, pp. 070013-1 to 070013-7, ISSN 0094243X, 15517616, SJR=0,15.

[16] D. Petrova, N. Nikolova and A.. Lengerov, Organizational design of the management system of the reengineered enterprise - Design and implementation, 11th International Scientific Conference "TechSys 2022" – Engineering, Technologies and Systems, AIP Conf. Proc. 2980, 070012-1–070012-8; https://doi.org/10.1063/5.0185274 , Published by AIP Publishing. 978-0-7354-4814-8/$30.00, pp. 070012-1 to 070012-8, ISSN 0094243X, 15517616, SJR=0,15.

[17] D. Petrova, Innovative Obsolescence in Mechanical Engineering and Singleness of Indicators, Vide. Tehnologija. Resursi - Environment, Technology, Resources, Volume 3, Pages 221 – 224, 2024, 15th International Scientific and Practical Conference on Environment. Technology. Resources, ETR 2024, Rezekne 27 June 2024 through 28 June 2024, ISSN 16915402, ISBN 978-171389957-0, DOI: https://doi.org/10.17770/etr2024vol3.8123.

[18] T. Rachovski, D., Petrova and I. Ivanov, Automated Creation of Educational Questions: Analysis of Artificial Intelligence Technologies and Their Role in Education, Vide. Tehnologija. Resursi - Environment, Technology, Resources, Volume 2, Pages 465 – 467, 2024, 15th International Scientific and Practical Conference on Environment. Technology. Resources, ETR 2024, Rezekne 27 June 2024 through 28 June 2024, ISSN 16915402, ISBN 978-171389957-0, DOI: https://doi.org/10.17770/etr2024vol2.8101.

[19] R. Rusev and V. Galabov, Structuring ofrational planet-lever mechanism for passing the weft through the weaving machines. "Mechanics of machines" 2002 pp.26 booklet 33.

[20] S. Singh, Theory of Machines: Kinematics and Dynamics, Pearson Education, India 2011

[21] S. Stefanov, Theoretical mechanics, statics, kinematics and dynamics, Sofia 2014.

[22] P. Stoyanov, Geometric precision synthesisof planar lever mechanisms. "Mechanics ofthe machines" 2002 p.56 vol. 33.

[23] G. Timofeev, Theory of Mechanisms and Machines, Moskow Uride 2010.