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Optimization of the Elevating Mass Balance Of the Anti – Aircraft Gun Bofors 40 mm L/70

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The reconstruction of the anti – aircraft gun's loader and the increase in its capacity leads to an elevating mass debarment in relation with the axis of the gun's trunnion which creates a need for balancing gear reconstruction. The elevating mass is completely balanced in all elevations and even throughout the recoil movements by two balancing gears. Elevation balancing gear is on the left side of the gun while recoil and elevation balancing gear is on the right side. The mass increase is happening on the far back side of the gun and leads to translation of center of mass which makes pulling effects of balancing gears negative for the balance of elevating mass. By creating a real 3D model of the gun, new mass and its center of gravity are found. Using that information and knowing characteristics of balancing gears makes it possible to reconstruct them and create an elevating mass equilibrium

Key words: **anti-aircraft gun, 40 mm caliber, reconstruction, automatic loader, balancing gear, system balance, mass balance, elevation.**

THE balancing mechanism (balancing gear) is designed to reduce the effect of the gun's weight by creating an opposing moment that is almost equal to the one gun creates. The balance, obtained with the mechanism, makes it possible for soldiers to use it almost effortlessly and reduces the strain put on the elevating mechanism. There are two types of equilibrium – static and dynamic. Static equilibrium is usually obtained by putting additional weight on the rear part of the gun, while dynamic equilibrium needs a balancing mechanism – balancing gears. Balancing gears can be pneumatic or spring operated [1].

According to the way the balancing gears produce the force that creates the equalizing moment they can be pulling or pushing balancing gears. Figures 1 and 2 show two types of balancing gears.

Relative to the trunnion's axis, and in accordance with the type, balancing gears can be put in front or behind the trunnion, under or above it. One end of balancing mechanism is always connected to the cradle while the other end is connected to the mounting body.

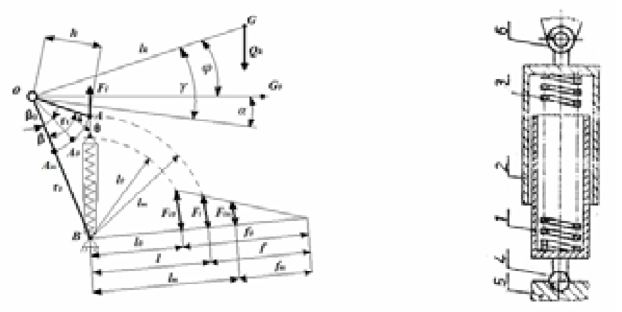

Figure 1. Pushing type balancing gear

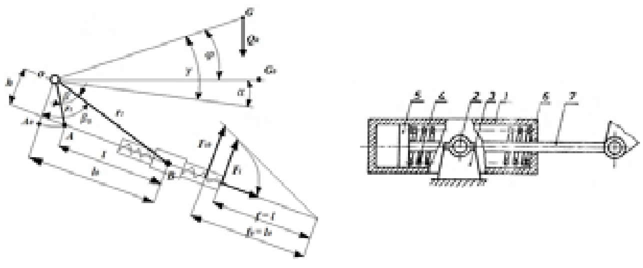

Figure 2. Pulling type balancing gear

Force of the equilibrator F_i with the arm h, relative to the axis of cradle trunnion O, creates equalizing momentum which is countering the momentum created by the weight of the gun's elevating parts. With the change of the elevating angle, size of the arm changes.

Pneumatic and hydro-pneumatic equilibrators are lighter and more compact than spring-loaded ones and they generate more force. The disadvantages are that the gas pressure depends on the outside temperature, which is why it is necessary to incorporate the temperature regulators, then the sealer of the balancing gear produces larger friction forces that can't be balanced when starting a movement in the opposite direction, they are less reliable in exploitation and have a more complex maintenance system.

In the case of a spring-loaded equilibrator of the pulling type, the problem is to provide enough space for rotating the oscillating cylinder, and the moment of the weight of the equilibrator relative to the shoulders of the cradle negatively affects the accuracy of the balance. Therefore, a pneumatic, pulling type, equilibrator is more often used. When designing spring and pneumatic balancing gears, it is necessary to predict the possibility of their adjustment during exploitation.

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Balancing gear calculation consists of equalizing two moments that occur and they are presented in Fig.3.

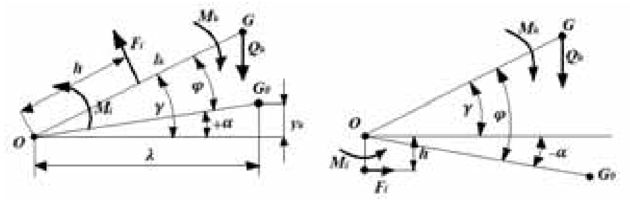

Figure 3. Force momentum representation

$$M_k = Q_k l_k \cos\gamma \qquad\qquad M_i = F_i h$$

$$Q_k l_k \cos\gamma = F_i h$$

where:
M_k –weight momentum of elevation parts,
M_i – equilibrator's momentum,
Q_k – weight of elevation parts,
l_k – distance between the trunnion and center of gravity of elevation mass,
γ –angle between horizontal plane and the direction in which the center of gravity lays,
F_i – force of the equilibrator,
h - arm of the equilibrator's force.

As seen from the Fig.3: $\gamma = \varphi \pm \alpha$,

where:
φ – elevation angle
α – angle between horizontal plane and the direction in which the center of gravity lays while $\varphi = 0^o$

Problem

Existing construction

The elevation trunnions of the gun are placed as far to the rear as possible, partly in order to obtain a low height of fire and thus increased stability, partly to facilitate loading at high elevations, the center of gravity of the elevating mass is thus situated in front of the trunnions. During firing the center of gravity moves along the axis of the barrel.

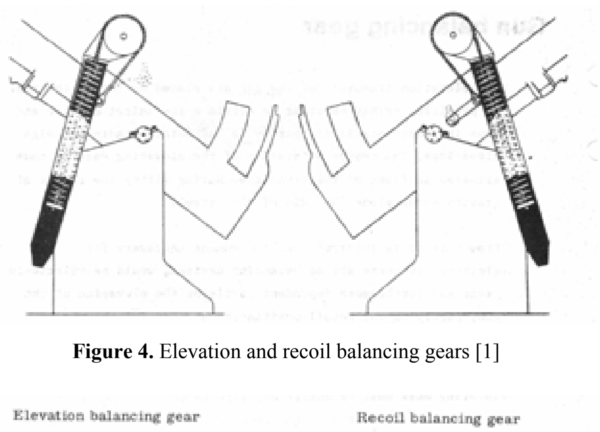

Figure 4. Elevation and recoil balancing gears [1]

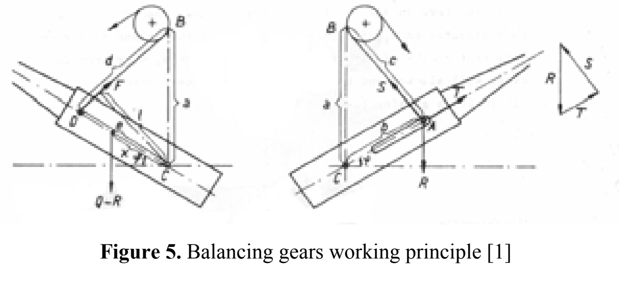

Figure 5. Balancing gears working principle [1]

In order to obtain equilibrium, even during firing, the gun has been equipped with two balancing gears. Both are designed with springs mounted in drums, one on each side of the mounting body. the springs are influenced by wires, which via wheels on the top of the gun are fastened to the elevation mass.

The wire of the left-hand balancing gear is fastened to the breech casing and is thus a pure elevation balancer. The wire to the right-hand balancer is fixed to the breech ring in a trunnion which, during the recoil action, runs in a groove in the breech casing. This balancer serves as both elevation and recoil balancer [2].

The principle of the design of the balancing gears is shown in Figures 4 and 5.

The effect of the new loader's mass on the equilibrium of gun's masses

Anti-aircraft gun has an ammunition loader consisting of supporting frames and a channel which leads ammunition into the gun's casing. Empty loader has a mass of 35 kg and its maximum capacity is 26 bullets.

New loader, with increased capacity, when empty has a mass of 80 kg and its new capacity is 44 bullets.

Most of its structure is placed on the rear part of the gun thus moving the center of gravity closer to the trunnions of the gun. This way the equilibrium is disturbed because now we have a bigger difference between weight momentum and equilibrator momentum.

Difference in momentum between the original gun and the new gun is shown on the graph in Fig.6.

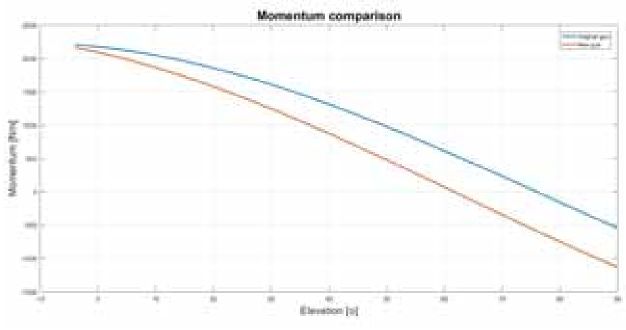

Figure 6. Momentum comparison of original and new gun

Solution suggestions

Equilibrators express their purpose by creating momentum that elevates the barrel, countering the lowering momentum that the weight of gun's elevation parts creates.

With new loader a negative momentum is created around the cradle's trunnion and the need for equilibrium requires reconstruction of existing equilibrators, or a different solution.

First, obvious, solution would be to move the part around which the wire, connected with springs, moves. This way the equilibrator would, after determined elevating angle, pull down the elevation mass instead of constantly elevating it.

Second solution would be to change the point of cord's connection with the gun.

Third possible solution is to make another equilibrator that would counter only the difference in momentum that new loader creates after a certain elevating angle.

3D model of the gun and springs testing

3D model of the gun was made using technical documentation and technical manual to simulate realistic mass distribution and to find the position of the center of mass (Fig.7).

Model was made using Inventor 2018 software package.

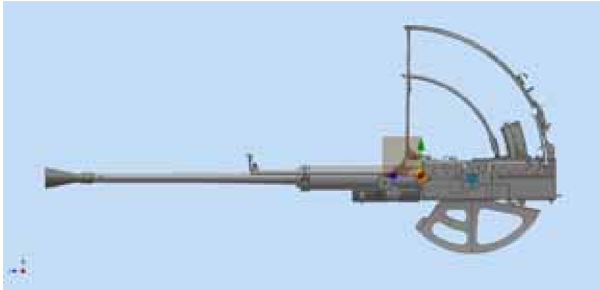

Figure 7. Model of original gun with center of gravity

Centre of gravity is positioned 395 mm ahead of the cradle's trunnion, and its mass is 575 kg.

To make equilibrators calculation possible the specifications of the springs were required. Since some of the values found in documentation were incorrect, measuring of spring characteristics was conducted.

Tests were conducted on electromechanical SCHENCK-TREBEL RM100 testing machine. During the test, two parameters were measured: force induced by compression of spring and the stroke of the device. The device stroke, with reference to the free spring length (L_0), was used to calculate the dependence of the force and length of the spring at the given moment.

Fig.8 shows tested springs and Figures 9-12 show graphs that were created in accordance with the results and respectively to the photo (from left to right).

Tables 1-4 show spring's minimum and maximum working forces. Tables show defined forces and measured forces for the start and the end of the working stroke.

Figure 8. Tested springs of the balancing gears

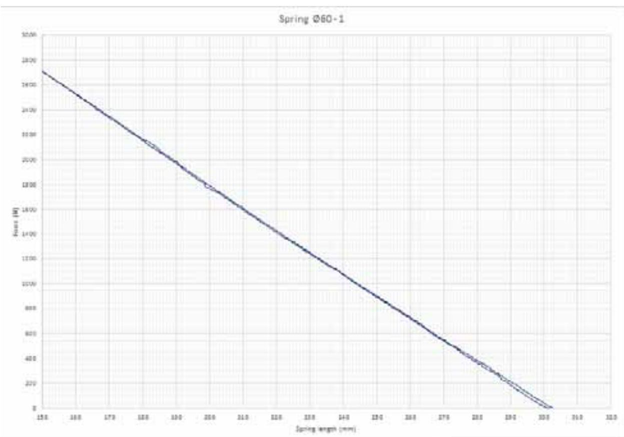

Figure 9. Inner spring 1

Table 1. Defined and measured forces for inner spring 1

Force (N)	
Defined	Measured
$484,61 \pm 48$	449,2
2779^{+138}_{-296}	2707

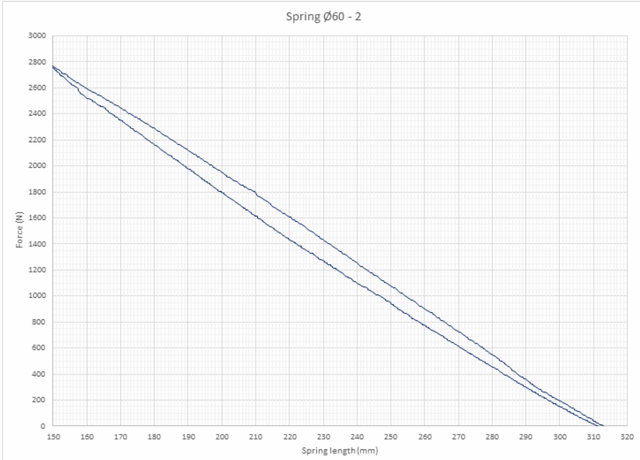

Figure 10. Inner spring 2

Table 2. Defined and measured forces for inner spring 2

Force (N)	
Defined	Measured
$484,61 \pm 48$	623,2
2779^{+138}_{-296}	2770,1

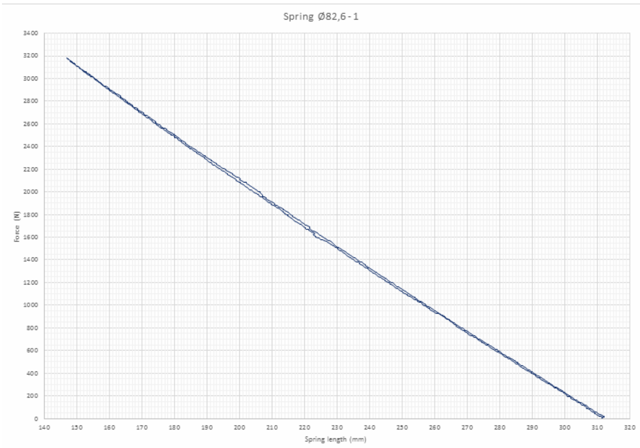

Figure 11. Outer spring 1

Table 3. Defined and measured forces for outer spring 1

Force (N)	
Defined	Measured
$652,74 \pm 70$	677,5
102,85	3134,3

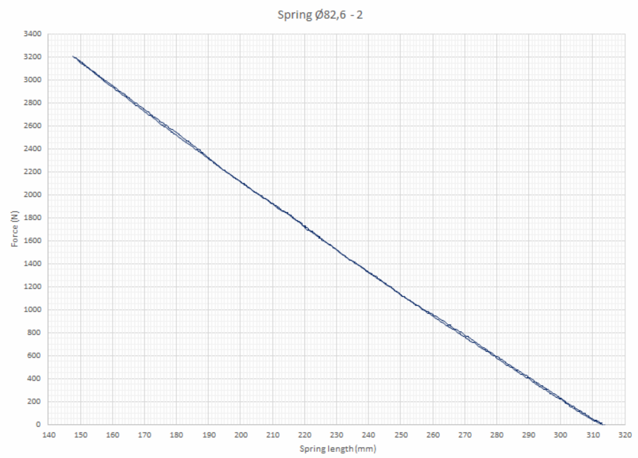

Figure 12. Outer spring 2

Table 4. Defined and measured forces for outer spring 2

Force (N)	
Defined	Measured
$652,74 \pm 70$	683,7
$53,46 \pm 7,91$	3179,1

Force change of the left equilibrator in accordance with elevation angle is shown on the graph in Fig.13.

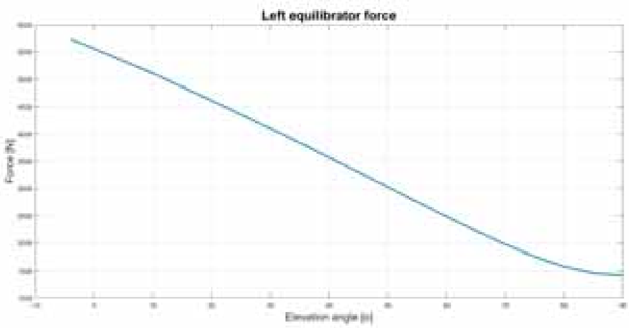

Figure 13. Change of the force relative to elevation angle

Calculation was conducted using data acquired from spring measuring, documentation and from 3D model of the gun.

Based on the calculation of equilibrators force, we further calculate the momentum this force creates around the axis of the cradle's shoulders.

Graphs in Figures 14 and 15 show the effect that momentum of equilibrators force has on the momentum that is created by the original gun's elevating mass with full loader – 26 bullets and the gun's elevating mass with fully loaded new loader – 44 bullets.

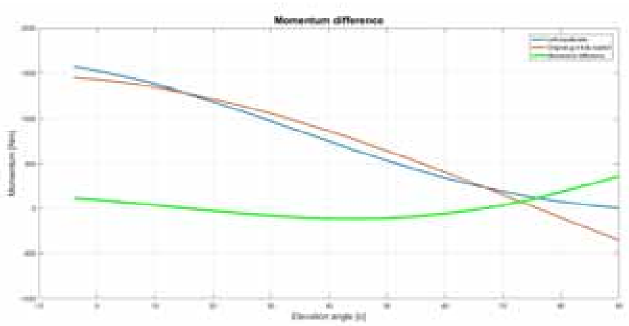

Figure 14. Effect of equilibrator on original gun

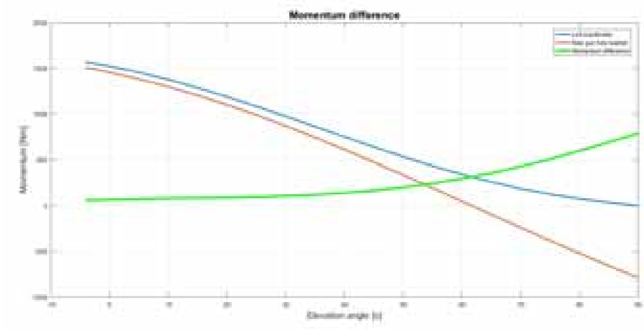

Figure 15. Effect of equilibrator on new gun

Model of the gun with the new loader and solution

Fig.16 shows 3D model of the gun with the new loader, without ammunition and with new center of gravity.

Figure 16. Center of gravity with empty new loader

Fig.17 shows 3D model of the gun with new loader loaded to full capacity with its new center of gravity.

Figure 17. Center of gravity with full new loader

Gun, equipped with new, empty, loader, has a mass of 621 kg and due to its construction a higher center of gravity. That effect is even greater when the gun is fully loaded.

To achieve equilibrium in all elevations it is decided to equalize momentum that gun has when the new loader is loaded to the half of its capacity because the difference between empty and fully loaded gun's momentum is too large.

Momentum difference that increases rapidly after elevation passes 40 degrees would be balanced (reduced) by designing another equilibrator that creates a momentum which forces the gun to lower its elevation.

Schematic design is shown in the Fig.18. Equilibrator should be set behind the gun's recoil equilibrator where there are no operating levers or anything that its design would compromise the use of the gun.

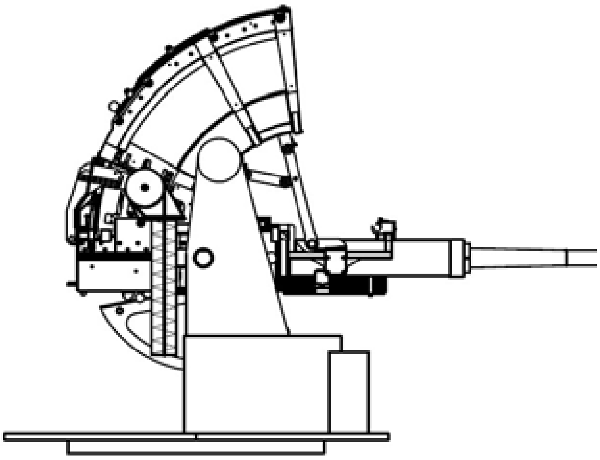

Figure 18. New equilibrator design

Conclusion

Design of the new loader lead to increase in momentum difference and thus disturbed the balance of the gun's elevation mass. Idea was to change original gun as little as possible so it could be used as it was whenever needed.

Three different solutions were proposed to reduce the momentum difference that occurs, but only one solution leaves the original construction of balancing gears intact.

First and second solution, to move the wheel that carries the wire and to move the connecting point of the wire with the gun have the same problem.

The force of the balancing gear will change its direction when needed and start to pull the gun to lower the elevation 2but the problem occurs when the momentum that the new loader creates becomes too great.

As the elevation rises the springs decompress and the force weakens. This leads to lower equalizing momentum of the balancing gear than the one needed. When the highest value of counter momentum is needed its value is the lowest and that is why these solutions are insufficient for balancing gears with these characteristics.

Third solution is the one with the most potential. Another equilibrator would counter the momentum of the new loader after the determined elevation and it would only effect that part of elevation.

Another positive thing about a third equilibrator is that the original construction stays intact which means that by excluding it, if needed, original gun could be used as it is.

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Optimizacija uravnoteženja nagibnog sklopa protivavionskog topa BOFORS 40 mm L/70

Rekonstrukcija punjača protivavionskog topa i povećanje njegovog kapaciteta dovodi do promene položaja centra mase nagibnog sklopa u odnosu na osu ramena kolevke topa te se stvara potreba za rekonstrukcijom izravnjača. Nagibni sklop topa, pri svim uglovima elevacije, čak i u toku procesa trzanja, uravnotežuju dva izravnjača. Izravnjač elevacije nalazi se sa leve strane dok se izravnjač trzanja i elevacije nalazi sa desne strane. Povećanje mase, usled rekonstrukcije, dešava se na zadnjem kraju topa pa se vukući efekat izravnjača negativno odražava na uravnoteženje nagibnog sklopa. Izradom 3D modela topa, dolazimo do vrednosti nove mase topa i novog položaja centra mase. Koristeći te podatke i znajući karakteristike izravnjača, možemo ih rekonstruisati i uspostviti ravnotežu nagibnog sklopa.

Ključne reči: **PA top, kalibar 40 mm, rekonstrukcija, automatski punjač, izravnjač, ravnoteža sistema, uravnoteženje mase, nagib.**

Оптимизация балансировочного наклонного набора зенитной пушки бофорс 40 mm L/70

Реконструкция зарядного устройства зенитной пушки и увеличение его мощности приводит к изменению положения центра массы наклонного узла относительно оси плечевой полости пушки, и возникает необходимость реконструкции выпрямителя. Наклонный набор пушки, на всех углах возвышения, даже и во время процесса подёргивания, уравновешен двумя выпрямителями. Выпрямитель возвышения расположен с левой стороны, а выпрямитель уравновешивания и выравнивания высоты - справа. Увеличение массы, из-за реконструкции, происходит на заднем конце пушки, и перетаскивание эффекта выпрямителя отрицательно отражает баланс наклонного узла. Создавая трёхмерную модель пушки, мы приходим к значению новой массы пушки и новому центрально-взвешенного положению массы. Используя эти данные и зная характеристики выпрямителя, мы можем восстановить их и установить баланс наклонного узла.

Ключевые слова: **зенитная пушка, калибр 40 mm, реконструкция, автоматическое зарядное устройство, выпрямитель, системный баланс, баланс веса, уклон.**

Optimisation d'équilibrage du mécanisme incliné chez le canon antiaérien BOFORS 40 mm L/70

La reconstruction du chargeur chez le canon antiaérien et l'augmentation de sa capacité amène au changement de la position du centre de la masse du mécanisme incliné par rapport à l'axe de l'épaule du berceau de canon de sorte qu'on a besoin de reconstruire le niveleur. Le mécanisme incliné du canon dans tous les angles d'élévation , même pendant le recul, est équilibré par deux niveleurs. Le niveleur d'élévation se trouve à gauche alors que le niveleur de recul et d'élévation est à droite. L'augmentation de la masse créée par la reconstruction se produit au bout l'arrière du canon de sorte que l'effet de traction de niveleur agit négativement sur l'équilibrage du mécanisme incliné. Par la fabrication du modèle 3D on obtient les valeurs de nouvelle masse de canon ainsi que la nouvelle position du centre de masse. En utilisant ces données et connaissant les caractéristiques du niveleur il est possible de les reconstruire et d'établir l'équilibre du mécanisme incliné.

Mots clés: **canon antiaérien, calibre de 40mm, reconstruction, chargeur automatique, niveleur, équilibre de système, équilibrage de masse, inclinaison.**