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Research paper

Dynamics of OSU-35 Naval Weapon System Ammunition Belts

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Abstract. The paper analyzes the dynamics of an ammunition belt feeding the 35 mm KDA naval cannon - an integral component of the Polish 35 mm Naval Weapon System (OSU-35). The study is concerned with an ammunition feeding mechanism designed and manufactured by Zakłady Mechaniczne "Tarnów" S.A. (Tarnów, Poland), and is part of the project entitled: *35 mm KDA automatic naval cannon with a ship-installed fire control system utilizing a naval version of the ZGS-158 Integrated Tracking Head with a fire control station*. The results of the above-mentioned analysis have confirmed that the design solutions satisfy the assumptions defined for the development of the 35 mm naval cannon being part of the OSU-35 weapon system.
Keywords: Naval Weapon System (NWS), naval cannon, 35 mm KDA, armament

1. INTRODUCTION

Over the years, as the weapons designs progressed, ammunition supply and storage methods have changed significantly to ensure reliable feeding. High rates of fire have always played an important role in military tactics. Piotr Wilniewczyc described this issue very accurately in the book entitled *Automatic weapons* [1]: *"By its very nature, machine guns shoot only as long as cartridges are delivered thereto. For proper feeding, the cartridges must be arranged so that the lifting and feeding device is capable of catching the next cartridge and sliding it into the cartridge chamber. The number of cartridges in the tray determines the length of the uninterrupted series, and thus largely and the fire power of a given weapon".*

In the traditional post-war Polish-language nomenclature [2], the term of "feeding weapons" is used to describe the process of transporting cartridges from a container (magazine, cartridge belt) to the barrel chamber (or revolver drum) of the weapon. The said process consists of three stages:

- moving the cartridge from the magazine to the weapon's feed mechanism, i.e. the loading space inside the weapon's receiver in which the cartridge is located before feeding. In the case of magazine-based feeding, the movement of cartridges is ensured by the energy of the magazine's spring, while belt-based feeding relies on the energy of the weapon's automatic system,
- feeding the cartridge, via the feeder, from the feed tray to the ramming position,
- ramming the cartridge, by the rammer, to the cartridge chamber (the bolt is usually used as the rammer).

In many types of weapons, feeding and ramming constitute one operation.

2. SUPPLYING AMMUNITION TO 35 MM KDA NAVAL CANNON [3]

The 35 mm KDA cannon is supplied with 35 × 228 mm rounds placed in a disintegrating belt made up of DM70 links (with an open link) (Fig.1).

The weapon is fed with ammunition as shots are being fired, and the process comprises all the steps that are necessary to prepare the cartridges stored in an ammunition belt for shooting.

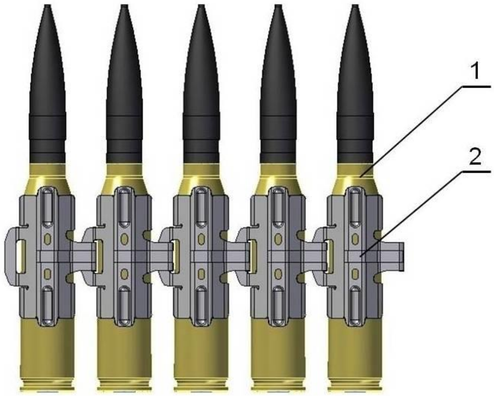

Fig. 1. Ammunition belt: 1 – 35 × 228 mm cartridge, 2 – DM70 link

The driving elements of the belt feeding system in the KDA 35 mm cannon have the form of rotary star feeders (star wheels) which are driven by a specific mechanism, located under the feed cover, using the reciprocating movement of the breech block (Fig.2). When firing in the continuous mode or in short bursts, the ammunition belt makes intermittent movements. The weapon's ammunition supply system transfers a series of repeating movement cycles to the ammunition belt. In the KDA 35 mm cannon, the first cartridge link is pulled by the star wheel of the feeding mechanism, thus moving the ammunition belt.

During the recoil of the breech block (its displacement to the rearmost position), the star wheel rotates by 30° and the ammunition belt moves by half its stroke, i.e. by 38.5 mm. Once the clearance between the first and second link has been eliminated, the second link starts to move as it is pulled. The links stop after colliding with each other, and some of the energy is dissipated due to the impact between the individual elements.

When the breech block moves to its frontmost position, the star wheel rotates by another 30° and the ammunition belt once again moves by half the stroke, i.e. by 38.5 mm.

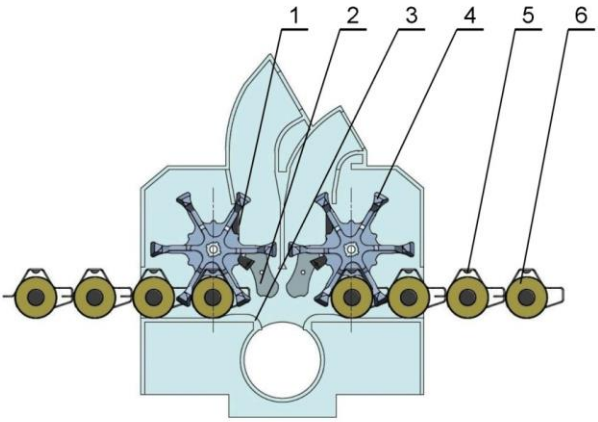

Fig. 2. Basic components of the KDA cannon feeder: 1 – feed tray (right/left), 2 – cartridge stripper (right / left), 3 – cartridge guide, 4 – feed star wheel (right / left), 5 – link, 6 - cartridge

During the movement of the breech block into the rearmost position, the feeder star wheel with the round place in a cartridge belt rotates by half the stroke.

The cartridge is removed from the belt by a stripper (Fig.3). When the breech block passes the cartridge guide, the cartridge falls between the edges of the cartridge guide (the cartridge is positioned on the ramming line).

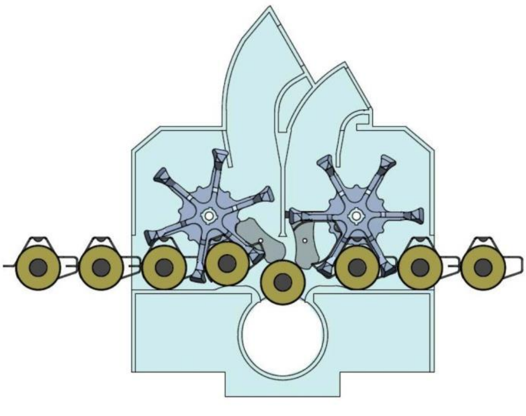

Fig. 3. Position of the KDA cannon feeder components when the breech block is in its rearmost position

When the breech block moves to the frontmost position, the cartridge is inserted into the cartridge chamber (Fig.4). The feeder star rotates by half the stroke, moving the ammunition in the cartridge belt. After the breech block reaches its frontmost position, the next cartridge is ready to be released from the ammunition belt.

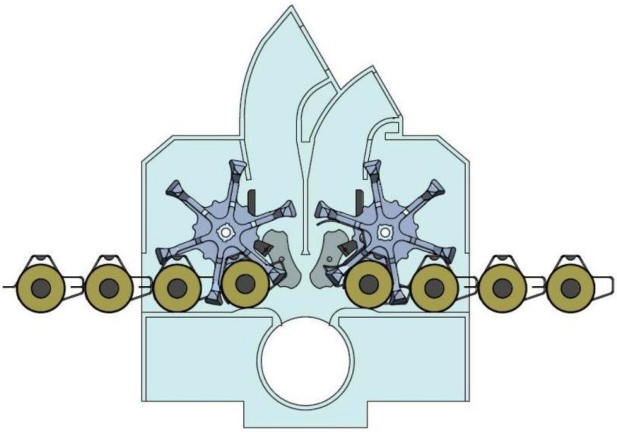

Fig. 4. Position of the KDA cannon feeder components when the breech block is in its frontmost position

When firing with short bursts or when using the continuous fire mode, the time during which the ammunition belt needs to be stopped (to lock the breech lock in the frontmost position, fire the primer and take a shot) should be taken into account. The ammunition belt is moved, during the firing cycle, in two steps - the star wheel of the rotor rotates, by 30°, twice per each shot. The ammunition belt' movement cycle is repeated automatically in the 35 mm KDA cannon.

3. SUPPLY AND STORAGE OF AMMUNITION IN OSU-35 [4, 5]

The right-hand side of the ammunition supply and storage system is described in this article, with the left-hand side being a mirror image of its right-hand side counterpart (Fig.5).

The movement of the ammunition belt can be divided into several stages:

Stage 1: The ammunition belt moves inside a flexible ammunition belt chute, between the cannon's feeder star wheels and the star wheels of the auxiliary cartridge feed mechanism.

Stage 2: The ammunition belt moves on the star wheels of the auxiliary ammunition feed mechanism.

Stage 3: The ammunition belt is moved from the drum ammunition magazine to the star wheels of the auxiliary ammunition feed mechanism.

Stage 4: The ammunition belt moves in the drum ammunition magazine.

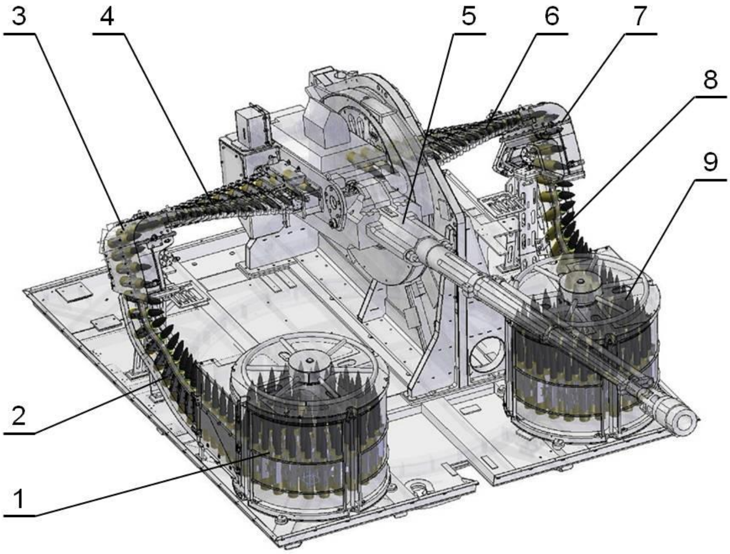

Fig. 5. Supply and storage of ammunition in OSU-35: 1 – right-hand drum ammunition magazine, 2 – right-hand rigid guide, 3 – right-hand auxiliary ammunition feed mechanism (belt booster), 4 – right-hand flexible ammunition belt chute, 5 – 35 mm KDA cannon, 6 – left-hand flexible ammunition belt chute, 7 – left-hand auxiliary ammunition feed mechanism (belt booster) 8 – left-hand rigid guide, 9 – left-hand drum ammunition magazine

The use of drums for ammunition storage (Fig.6) significantly improves cartridge packing density. As DM70 links are flexible and allow for relative rotation in two perpendicular directions, the ammunition belt can be more densely packed in the drum than in a linear magazine.

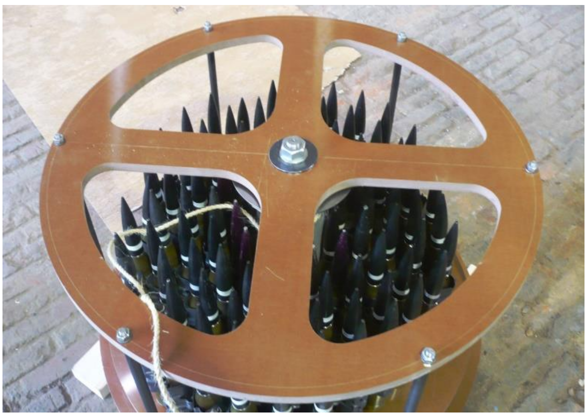

Fig. 6. Drum ammunition magazine model

Assuming that the dimensions of a single link equal 77 × 65 mm (Fig. 7) and that the diameter of the ammunition pocket Ø = 54.7 mm, linear packing density of the cartridges g_1 can be calculated with the use of formula (1).

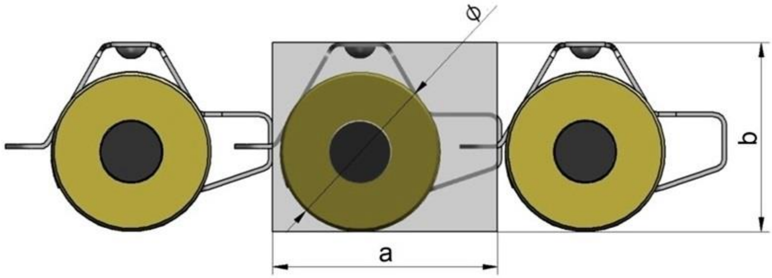

Fig. 7. Linear ammunition belt arrangement

$$g_1 = \frac{\frac{\pi Ø^2}{4}}{ab} = 0.47 \tag{1}$$

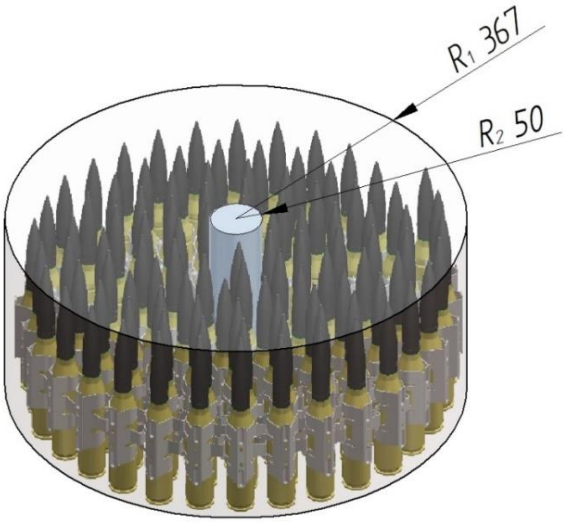

Fig. 8. Spiral ammunition belt arrangement

The dimensions of the cross-section of the ammunition drum's working section (circular ring) are R_1 = 50 mm and R_2 = 367 mm (Fig 8), meaning that packing density g_2 may be calculated, for 100 spirally arranged cartridges, with the use of formula (2).

$$g_2 = \frac{100\frac{\pi Ø^2}{4}}{\pi R_2^2 - \pi R_1^2} = 0,57 \tag{2}$$

Based on the results of calculations made with the use of formulas (1) and (2), one may conclude that a 9.6% packing density advantage exists when using a spirally arranged ammunition belt.

4. DM70 LINK STIFFNESS

We consider the ammunition belt to be a series of connected springs, with the stiffness coefficient of a single link c_0 being its characteristic parameter (Fig. 9).

Fig. 9. Ammunition belt (link considered to be a spring element)

By measuring (Fig. 10 and Fig.11) link elongation ΔS_0 caused by tensile force F_0, link stiffness [6] coefficient c_0 can be determined from the following relationship (3):

$$c_0 = \frac{F_0}{\Delta S_0} \tag{3}$$

where:
F_0 – tensile force applied to one ammunition belt link,
ΔS_0 – elongation of one ammunition belt element (increasing the stroke of the ammunition belt when tensile force is applied).

Fig. 10. Stretching a link with a cartridge

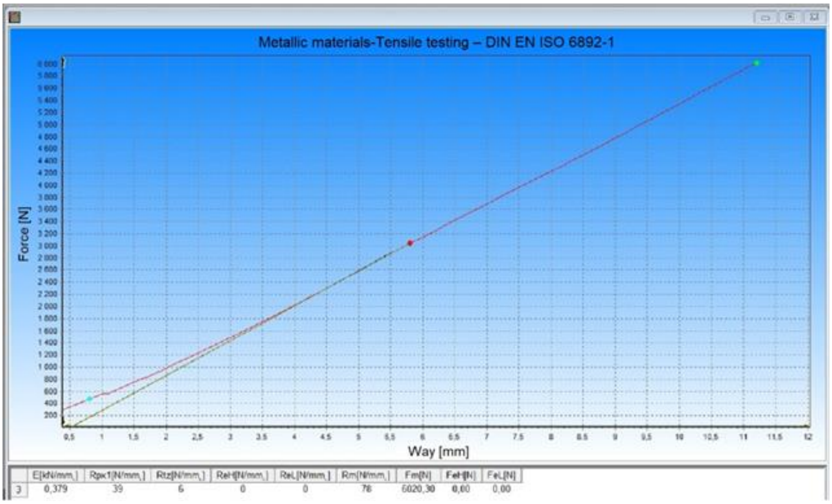

Fig. 11. Ammunition link stretch plot

The mean stiffness coefficient of one ammunition link with a cartridge, determined based on 5 tests, equals c_0=369.4 N/mm

5. FEEDING AMMUNITION TO THE 35 MM KDA CANNON

An ammunition belt consists of cartridges placed in separate links. The structure of each link has a strictly defined stiffness, i.e. the ability to deform when a tensile force is applied thereto, and to regain its initial state when the force is removed. The ammunition belt has the properties of a compensating connection due to the play existing between adjacent links. These two factors determine the dynamics of the ammunition belt's movement. Operational dynamics of the ammunition belt must be such that no forces exceeding the elastic strength of the links are exerted [7].

In accordance with the above-mentioned assumptions, the ammunition belt will be considered to have the form of a sequence of cartridges connected by elastic elements, each of which has a specified clearance of 5 mm. The distance between the axes of adjacent cartridges is referred to as ammunition belt pitch and amounts to 77 mm.

As the feeding mechanism operates and the ammunition belt begins to move, backlash between the first and second cartridge is eliminated and the second cartridge starts to move as well. Furthermore, as the first cartridge has achieved a certain rate of speed and the second one is still at rest, the movement of the second cartridge begins with a specific impact force exerted. Then, the third, fourth and subsequent cartridges are put into motion – all with that impact force. The cartridges down the belt fail to immediately reach the same speed at which the first cartridge is moving.

Due to the discrepancies in the speed of the cartridges, the links of the ammunition belt are deformed. This deformation, as mentioned earlier, is within the elastic limits of the link. After the first link moves one step, it stops and the remaining cartridges linked thereto continue to move inertly. The link with the second cartridge hits the first stationary link, bounces off and slack is created between those two links, with the subsequent links continuing to move. Individual links with cartridges stop, leading to the removal of tensile forces between the individual links of the ammunition belt. That is how ammunition belts move while the weapon is firing. Individual links with cartridges are put into motion, one after the other, with blows, and the movement of the ammunition belt is accompanied by the stretching of the links and the appearance of elastic forces in the links [7, 8].

In order to simplify the description of the ammunition belt's motion, the following assumptions are made (which do not distort, in practice, the laws according to which the belt is moving while firing): at the beginning of the firing sequence, the ammunition belt is at rest. It is considered to be a spring element, i.e. a spring with tensile loads only. Energy losses caused by lateral movements of the belt and losses resulting from ammunition belt impacts are disregarded.

Fig. 12. Ammunition belt as a spring element

The ammunition belt was assumed to be an elastic element with uniformly distributed mass and elastic properties corresponding to the characteristics of the individual belt links (Fig.12). With this assumption, the dynamic force F_{Dt} created in the individual sections of the belt during its movement was determined based on the wave displacement of elastic deformations. Such an assumption, considering that the ammunition belt is a spring element, seems to be fully justified. Unit mass of a specific section of the ammunition belt is denoted by p (4):

$$p = \frac{m_t}{S_t} \tag{4}$$

where:

$m_t = m_0 + m_n$ - mass of the link with a cartridge
m_0 – ass of the link
m_n – mass of the cartridge
S_t – ammunition belt pitch

Unit rigidity of the ammunition belt μ can be defined as (5):

$$\mu = \frac{F_t}{\varepsilon} \tag{5}$$

where:

F_t – dynamic force in the link
ε – elastic deformation of the link (6)

$$\varepsilon = \frac{\Delta S_t}{S_t} \tag{6}$$

Expressing the unit rigidity by the ammunition belt pitch (7):

$$\mu = \frac{F_t}{\Delta S_t} S_t = c_0 S_t \tag{7}$$

Analysis of differential deformations $u(x,t)$ along the ammunition belt leads to the creation of the wave equation [9] having the following form (8):

$$\frac{\partial^2 u}{\partial t^2} = \frac{\mu}{p}\frac{\partial^2 u}{\partial x^2} \tag{8}$$

Propagation velocity of the V wave is the square root of factor (9) before $\frac{\partial^2 u}{\partial x^2}$

$$V = \sqrt{\frac{\mu}{p}} \tag{9}$$

By substituting (4) and (7) to (9) (10):

$$V^2 = \frac{\mu}{p} = \frac{c_0 S_t}{\frac{m_t}{S_t}} = \frac{c_0 S_t^2}{m_t} \tag{10}$$

Expression for the momentum of the mass of the cartridge with the link (11):

$$P^2 = m_t^2 V^2 = c_0 m_t S_t^2, P = \sqrt{m_t c_0} S_t \tag{11}$$

From Newton's second law of dynamics $\left(\frac{dP}{dt} = F_{\mathrm{t}}\right)$ (12):

$$F_{\mathrm{Dt}} = \frac{dP}{dt} = \sqrt{m_{\mathrm{t}} c_o} \frac{dS_{\mathrm{t}}}{dt} = \sqrt{m_{\mathrm{t}} c_0} V_{\mathrm{t}} \quad (12)$$

where:

F_{Dt} – dynamic force of the ammunition belt
c_0 – rigidity of the ammunition belt link
V_{t} – speed of the ammunition belt movement

The dynamic force of the ammunition belt's resistance F_{Dt} does not depend on the number of cartridges in the belt, but on the elastic properties of the belt and the speed of its movement.

This proves the wave-like nature of the spread (propagation) of the deformation along the belt. In addition to the dynamic force created by the belt's resistance, static belt resistance forces F_{St} are present as well.

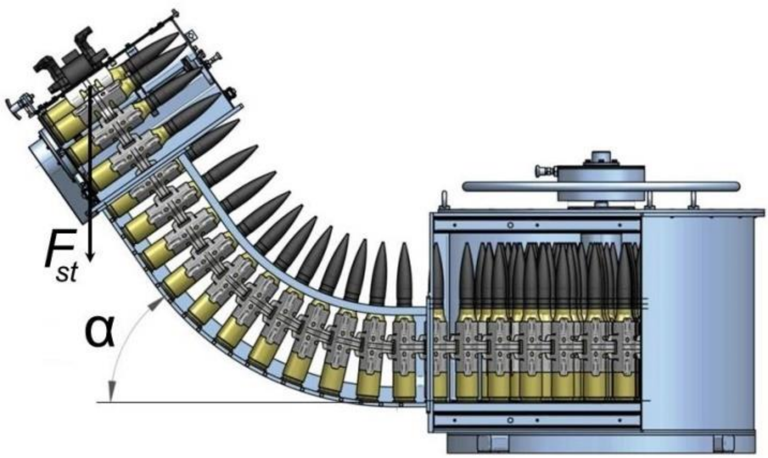

Fig. 13. Ammunition supply and storage mechanism

The static resistance force of the ammunition belt was defined as the resistance force of the belt (Fig. 13) which depends on the weight of the part of the belt moved to a given height and the friction force of the belt (13).

$$F_{\mathrm{St}} = (m_0 + m_{\mathrm{n}})\, n_{\mathrm{t}} g \sin\alpha \; + \; (m_0 + m_{\mathrm{n}})\, n_{\mathrm{t}} g\, f \cos\alpha \quad (13)$$

where:

n_{t} – number of cartridges in the inclined portion of the belt
α – angle of inclination of the cartridge guide
f – friction coefficient
g – gravitational acceleration

Total force generated in the ammunition belt is the sum of dynamic and static forces (14, 15):

$$F = F_{\mathrm{Dt}} + F_{\mathrm{St}} \tag{14}$$

$$F = \sqrt{c_{\mathrm{t}}(m_0 + m_{\mathrm{n}})}V_{\mathrm{t}} + (m_0 + m_{\mathrm{n}})\, n_{\mathrm{t}} g \sin\alpha \; + \; (m_0 + m_{\mathrm{n}})\, n_{\mathrm{t}} g\, f \cos\alpha \tag{15}$$

The power required to move the belt when the cannon is firing is described by formula (16):

$$P = kFV_{\mathrm{t}} \tag{16}$$

where: k – energy transfer coefficient.

By substituting (15) to (16) (17):

$$P = k\left(\sqrt{c_{\mathrm{t}}(m_0 + m_{\mathrm{n}})}V_{\mathrm{t}} + (m_0 + m_{\mathrm{n}})\, n_{\mathrm{t}} g \sin\alpha \; + \; (m_0 + m_{\mathrm{n}})\, n_{\mathrm{t}} g\, f \cos\alpha\right)V_{\mathrm{t}} \tag{17}$$

The feeding speed of the ammunition belt was expressed by the rate of fire T and the pitch of the belt S, taking into account its stretching ΔS (18):

$$V_t = \frac{S + \Delta S}{\frac{60}{T}} \tag{18}$$

where T − cannon's rate of fire expressed in the number of shots per minute

$$\Delta S = \frac{F}{c_{\mathrm{t}}} = \sqrt{\frac{(m_0 + m_{\mathrm{n}})}{c_{\mathrm{t}}}}V_{\mathrm{t}} + \frac{(m_0 + m_{\mathrm{n}})\, n_{\mathrm{t}} g \sin\alpha \; + \; (m_0 + m_{\mathrm{n}})\, n_{\mathrm{t}} g\, f \cos\alpha}{c_t} \tag{19}$$

Speed of the ammunition belt movement (20):

$$V_{\mathrm{t}} = \frac{S + \frac{(m_{\mathrm{o}} + m_{\mathrm{n}})\, n_{\mathrm{t}} g \sin\alpha \; + \; (m_0 + m_{\mathrm{n}})\, n_{\mathrm{t}} g\, f \cos\alpha}{c_{\mathrm{t}}}}{\frac{60}{T} - \sqrt{\frac{(m_0 + m_{\mathrm{n}})}{c_{\mathrm{t}}}}} \tag{20}$$

Table 1. Data used for calculations

No	Data	Value
1	Mass of a link	m_0 = 0.176 kg
2	Mass of a cartridge	m_{n} = 1.46 kg
3	Pitch of the ammunition belt	S = 77 mm
4	Link stiffness	c_0 = 398 n/mm
5	Gravitational acceleration	g = 9.81 m/s^2
6	Inclination angle of raised ammunition	α = 55^0
7	Number of cartridges being lifted	n = 10
8	Friction coefficient	f = 0.5

The elastic deformation occurring in the leading link as the ammunition belt is moving is not even close to the elastic limit of the link verified on a test bench.

Table 2. Dynamic and static forces, as well as elastic deformation of the link:

No	Data	Calculated result
1	Mass of link with a cartridge	m_t = 1.636 kg.
2	Dynamic force in the ammunition belt	F_{Dt} = 569.7 N
3	Static force present in the ammunition belt	F_{St} = 177.5 N
4	Total force present in the ammunition belt	F = 747 N
5	Deformation of the leading ammunition link	ΔS = 1.88 mm
6	Belt movement speed at a firing rate of 550 $\left[\frac{shot}{min}\right]$	V_t = 0.706 m/s
7	Elastic deformation of the link	ε = 2.44 %

6. CONCLUSIONS

The movement of an ammunition belt depends on many parameters related to the links, the elastic characteristics of the belt itself as well as additional resistance and time between the individual shots fired. The value of our work consists in taking into account the increase in belt stroke resulting from its stretching. Mechanisms used for supplying and storing ammunition, with a particular emphasis on supplying ammunition placed in an ammunition belt, are one of the most important components in the entire fire sequence. Their design requires the development and application of solutions that will not be a cause of the weapon's malfunction.

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Analiza pracy taśmy amunicyjnej w 35 mm armacie KDA Okrętowego Systemu Uzbrojenia OSU-35

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Streszczenie. W artykule przedstawiono analizę pracy taśmy amunicyjnej zasilającej 35 mm armatę KDA, będącą integralną częścią 35 mm Okrętowego Systemu Uzbrojenia (OSU-35). Analizę pracy taśmy amunicyjnej przeprowadzono dla systemu zasilania amunicją, opracowanego i wykonanego w Zakładach Mechanicznych „Tarnów" S.A. Do analizy przyjęto taśmę amunicyjną jako element elastyczny o równomiernie rozłożonej masie i właściwościach sprężystych odpowiadających poszczególnych ogniw taśmy. System donoszenia i magazynowania amunicji w w tej armacie został poddany badaniom lądowym i morskim odzwierciedlającym rzeczywiste warunki pracy w czasie eksploatacji. Praca przesuwania taśmy amunicyjnej zależy od wielu parametrów: skoku taśmy, charakterystyki sprężystości taśmy, dodatkowych oporów i czasu między strzałami. Wartość pracy należy określać z uwzględnieniem wzrostu skoku taśmy wynikającego z jej rozciągania. Mechanizmy zasilania i magazynowania amunicji, a w szczególności zasilanie amunicją umieszczoną w taśmie amunicyjnej, należą do najbardziej odpowiedzialnych zespołów w czasie prowadzenia ognia, ich konstrukcja wymaga opracowania i zastosowania takich rozwiązań, które nie będą przyczyną niesprawności działania broni.

Słowa kluczowe: uzbrojenie, uzbrojenie morskie, Okrętowy System Uzbrojenia, armata morska, KDA