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ALARM SYSTEMS FOR THE PROTECTION OF LONG SECTIONS OF THE STATE BORDER: A RETROSPECTIVE REVIEW OF THEIR USE IN UKRAINE IN THE PERIOD OF 1955–2000

A retrospective review of the signaling devices of protection of long sections of the state border used in Ukraine in the period 1955–2000 is carried out. The study pays special attention to the alarm systems and complexes used in the protection of the state border during the Cold War and in the post-soviet period, in particular, the S-100 systems "Skala", S-175 "Gardina" and complexes "Okean", KS 185 "Gobi".

Keywords: *state border, protection of long sections, retrospective review, signaling device, signaling complex, alarm system.*

Statement of the problem. Wire alarm barriers to protect long sections of border still remain one of the symbols of the "Iron Curtain" and are associated with the USSR during the Cold War as a sign of the ideologically insurmountable isolation of the Warsaw Pact from the democratic world, especially from the West. The "Iron Curtain" significantly impeded socio-cultural, technological, financial and information exchange between the countries of the "socialist camp" and democratic countries.

Thus, after the end of the Second World War and with the beginning of the Cold War, the ussr took measures to strengthen the protection of the state border, in particular by installing alarm equipment. The SV-1(2), "Rubin", S-12 "Tantal" and the most widely used barrier alarm system, "Klen-M", were installed and put into service in 1947.

However, the most widespread alarm system for the protection of long sections was used in the second half of the 1950 s after the adoption of the system S-100 "Skala". It was from that time until the mass decommissioning of long-distance signaling systems in the 2000 s that it seems appropriate to study the chronology, characteristics, and capabilities of each specific model used to protect long sections of the state border.

Analysis of recent research and publications. The historical aspects of the use of alarm systems to protect long sections of Ukraine's land border have not been adequately studied. This is due to the narrow profile of the research, as most of the works related to border protection focused on other issues of border security and safety, leaving out specific aspects of the use of alarm systems for the protection of long sections of the border. The lack of attention to this topic is the result of the limited amount of specific scientific material.

An engineering study on the design of border passive barrier systems on the Ukrainian-russian border was carried out in 2015 by scientists from the National Academy of the State Border Guard Service of Ukraine and employees of the company "Kordon Avia Service".

Papers [1, 2, 3] substantiate the system of requirements for the structure of technical means of engineering and technical control over land sections of the state border. The author of publication [4] substantiated the software solutions necessary for the formation of an effective distributed control system.

However, these studies highlight the use of alarm systems for the protection of long sections. There is a lack of domestic research that would examine in more detail and systematically in historical retrospect the use of alarm equipment for the protection of long sections in the protection of the state border on Ukrainian territory in the period 1955–2000.

The purpose of the article is to conduct a retrospective review and analysis of the capabilities of alarm systems for protection of long sections of the state border used in Ukraine in the period from 1955 to 2000, and also to study their evolution in the context of development of the state border protection technologies.

The general methodological basis for the study of alarm systems for the protection of long sections of the state border in Ukraine in the period 1955–2000 is the method of historicism, which was used to analyze the evolution and development of these devices. To achieve this goal, retrospective and technical analyses were chosen.

The retrospective analysis was used to recreate the technological development of alarm systems for the protection of long sections of the border in the specified period, in particular, to study changes in design solutions. The analysis made it possible to find out the reasons for the emergence of alarm systems for the protection of long sections of the border, which were associated with changes in the political situation in the world. The technical analysis was conducted to assess the main parameters of the alarm systems (length of the protected section (border), probability of detecting intruders, type of linear section alarm sensor, power supply (type, rating), information capacity, and the impact of external factors on their effectiveness. This made it possible to compare different models of long-distance signaling used at the border.

Summary of the main material. The general purpose of alarm systems for the protection of long sections of the state border is to provide timely information about the intruder's overcoming of the linear part of the alarm barrier.

After the collapse of the Soviet Union, Ukraine inherited alarm systems and long-distance security systems installed on the western state border with the Republic of Poland, the Czech and Slovak Federal Republic (since 1 January 1993 – the Slovak Republic), Hungary and Romania. Such means included the S-175 "Gardina" system, "Okean" and KS-185 "Gobi" [5, 6]. These systems and complexes represented a certain stage in the development and improvement of alarm equipment of this type.

Thus, in 1955, the kgb border troops of the ussr adopted the S-100 "Skala" long-distance alarm system. It consisted of a station part (control panel in the premises of the border outpost); line equipment (10 line units in sealed housings and 2 two-wire connecting lines up to 15 km long); line part (wire alarm barrier of the electric contact type).

The linear part (alarm barrier) was a wire fence on wooden supports (distance between them 3 m) with a total height of up to 2.5 m with a canopy (Figure 1). The web of the alarm barrier was formed by conductive threads that formed a connection with the same electrical resistance. The barrier had 25 horizontal threads of galvanized barbed wire on one side and two diagonal threads on the other. Visors were attached at the top in case the top 5 strands were broken or adjacent strands were shorted under a force of up to 400 N, which would have happened if someone had climbed over the barrier.

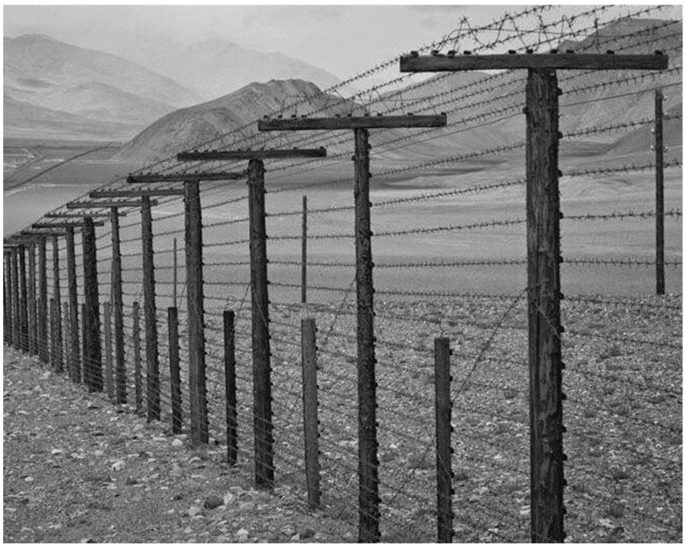

Figure 1 – Security barrier of the S-100 "Skala" alarm system

The linear part of the S-100 consisted of 20 separate sections up to 650 m long (but usually up to 500 m), which made it possible to control a total section with a maximum length of 13 km. Each of the 20 sections was assigned a specific electrical resistivity reference. The identification of an individual triggered section was based on its resistance value. In this case, the triggering could be caused by the short circuit or breakage of barbed wire in certain sections of the linear part. The direction of movement of the intruders was not automatically determined, so a 6–12 m wide control track strip (CTS) with a unique surface profile was arranged on the ground along the alarm barrier. This ensured fixation of the track of the trespasser(s) on the ground made it possible to identify their features and complicated the possibility of making tracks and using tricks by trespassers. In places where it was not possible to set up a CTS, S-100 alarm barriers were placed in two lines, which helped determine the direction of movement of the offenders by the order of receipt of signals about the triggering of the relevant sections of the lines.

The S-100 system was electromechanical, and in the event of a wire short circuit or break (indicating a potential violation of the state border), a special device on the control panel used a stepper motor to insert the appropriate reference resistor into the circuit. If the resistances matched, an audible alarm was activated, and the corresponding number of the section where the triggering occurred was displayed on the control panel.

The disadvantage of the S-100 was its poor quality. For example, due to unreliable electrical contacts, additional resistance could arise in the circuit, causing the system to incorrectly determine the number of the triggered area.

In addition, the S-100 had a certain negative image even before it was deployed on the state border, as it was used to guard the perimeters of prison zones and camps in the former ussr. However, at that time, ideological aspects were a priority, not image issues.

In 1975, to replace this alarm system, a more advanced system S-175 "Gardina" was developed and adopted in 1979. In a relatively short period of time, it became the most widely used alarm system in the protection of the state border of the ussr, in particular with Romania, Hungary, Czechoslovakia and Poland. This system made it possible to control a border with a total length of up to 20 km, which was divided into two flanks of up to 10 km. Each of these flanks consisted of 20 sections of 500 m each. The "Gardina" system was capable of controlling 4 electromechanical locks on the gate. In appearance, the S-175 security barrier was similar to the S-100 barrier, but the new signaling system had a different number of barbed wire strands (24 in the barrier, 6 on the visor), as well as polyethylene insulators for attaching metal barbed wire strands. Figure 2 shows the current appearance of the C-175 security barrier.

Figure 2 – Alarm barrier of the S-175 "Gardina"

Compared to the S-100, the S-175 achieved a significant increase in reliability, reduced power consumption and cost per hour, and increased the length of the security boundary.

The principle of detecting a violation remained the same as in the S-100 – electrocontact (short circuit of neighbouring wires of the alarm barrier or their breakage), but the registration equipment in the form of an electromechanical sensor became more sensitive and noise-resistant.

The electromechanical sensor sent sensing pulses with amplitude of up to 50 V and duration of about 1 ms with a period of several seconds to two adjacent sections of the security barrier through ballast resistors. The pulses that passed through all the signal threads (barbed wire) were monitored for amplitude in the range of up to 25 V. At the same time, the insulation resistance between the live and grounded threads had to be at least 130 Ohms at any point of the security barrier. Along with the S-175 barrier, a CTS was mandatory.

The S-175 alarm system consisted of three main parts:

1) station equipment, which also included a power supply subsystem, two connecting lines on the left and right flanks (underground cable, where one pair was for information and the other was used for power supply), Figure 3;

Figure 3 – Station equipment of the S-175 "Gardina" alarm system

2) linear equipment, which included up to 20 linear units and the same number of distribution boxes (they were usually located every 1 km), Figure 4;

3) alarm fence consisting of 20 sections of 500 m in length and electromechanical sensors of the electrocontact type, Figure 2.

The S-175 was powered by a 220 V network or by 2 alkaline batteries with a voltage of 22...28 V and a capacity of 60 Ah.

Figure 4 – Linear unit and distribution box of the alarm system S-175 "Gardina"

To open the electromechanical lock, a signal lasting about 10 seconds was given, during which it could be disengaged. The number of passages controlled in the alarm barrier could be no more than 4, and the status of the electromechanical lock was monitored by station equipment.

The disadvantages of the S-175 include the following.

1. The electrocontact type alarm barrier required systematic and time-consuming maintenance, which included replacing or cleaning rusty wires, soldering twists, and mowing the grass under the alarm barrier. However, if this maintenance is not carried out, the electromechanical detector will not work in 2–3 months (depending on humidity). As a rule, polyethylene insulators were used for up to 3 years, during which time they deteriorated (burst) under the influence of frost and sun. Thus, the reliability of the S-175 significantly depended on timely and high-quality maintenance, servicing and routine repair of the alarm barrier.

2. Insufficient resistance of wooden supports to the environment (in dry areas, their service life reached 15 years or more, and in marshy areas – only 5 years). Wooden supports and canopies were treated with creosote, which provided the necessary insulating and preservation properties. However, creosote is toxic and harmful to human health.

3. Low information capacity: information about overcoming the alarm barrier could be received from 20 sections of 500 m, but it was not possible to determine the direction of movement of the offenders without using a CTS. To assess the information capacity of this alarm system, a formal dependence can be used [7, 8, 9]:

$$I = K \cdot \log(N_T N_W N_D).$$

The number of time degrees of space affects the information capacity of security equipment, but it must be taken into account where time parameters are used to generate alarm signals, for example, the delay time of the received signal in relation to the emitted signal. Some of the existing technical means do not use the time characteristics of the signal, and accordingly, when determining the information capacity, the time degrees of freedom will be equal to $N_T = 1$.

In technical security means, spatial parameters were used most often in relation to the fact of violation. For example, alarm devices that provide information only about the probable fact of a violation have an information capacity of bits, but the C-175, in addition to the presence of a violation, had the functional ability to identify one of 40 areas over a length of 500 m where the violation occurred.

In security equipment that detects the fact of a violation and measures the distance to the violator, the number of types of degrees of freedom will be equal to $N_D = 2$ by $N_T = 1$, $N_W = \frac{L}{\Delta L}$ (L – length of the controlled border; ΔL – error in range measurement). The S-175 system belongs to such means, and its information capacity is as follows:

$$I = K \log_2\left(\frac{2 \cdot L}{\Delta L}\right) I = \log_2\left(\frac{2 \cdot 20000}{500}\right) = 6{,}32. \quad (2)$$

4. The need to equip and constantly maintain the CTS in good working order to detect signs of violations in a timely manner (place and time of violation, number of violators, direction of their movement, characteristics, etc.) required significant expenditure of various types of resources.

5. The cost of station equipment S-175 was 30 times higher than the cost of the S-100.

It should be noted that additional alarm sensors could be connected to the S-175. This ensured the probability of detecting a violation within $P = 0{,}90...0{,}95$, which is significantly higher than the performance of the main electromechanical sensors of the electrocontact type ($P \approx 0{,}7$), due to the use of other "more reliable" physical principles of operation. Such additional sensors were single-position or two-position radio-beam alarm systems, vibration alarm systems.

Radio-beam alarm systems allowed monitoring the border up to 250 m, but the increased specific power of these devices required a separate (additional) power supply, and their operation was affected by nearby vegetation, birds, and animals, which led to false alarms.

Linear vibration (vibration-seismic) alarm systems were designed to detect attempts to dig under the S-175 security barrier. The length of the boundary controlled by the vibration sensor was 1000 m (2 flanks of 500 m each). The sensing element of the vibration sensor was a triboelectric cable, hidden in a metal hose to protect it from the environment. The electronic unit of the sensor was located next to the linear unit S-175 and was powered by a 9 V DC or 36 V AC source. However, the sensitivity of the vibration device was low, and, as it turned out in practice, the detection of a digging occurred only in the case of direct mechanical impact on the metal hose.

Another vibration alarm sensor was the "Tangens". Its sensing element was also a triboelectric cable, but it was used to block the gates in the S-175 security barrier, as they could be overcome by climbing over without triggering an alarm. The triboelectric cable of the "Tangens" vibration detector was attached to the gate leaf and canopy using special clamps.

Another vibration alarm device was the "Gavot" sensor, which was designed to block metal grates installed at small water crossings with a flow velocity of up to 2 m/s. The sensing element of this sensor was a piezoelectric element, which was installed on each section of the alarm barrier, connected by special couplings. The electronic unit of the "Gavot" vibration detector generated a signal in case of dismantling of the security barrier, its sawing or dismantling of the sensitive element. Interference resistance was ensured against small objects that could cause false alarms (branches, debris, etc.). The "Gavot" sensor could monitor a river up to 30 m wide.

Despite its shortcomings, the S-175 system was used to protect the state border of Ukraine in the 1990s and until the early 2000s.

Along with this, in 1981, the alarm complex "Okean" was adopted by the border troops. Compared to the S-175 system, this complex operated on different physical principles – by registering changes in electrical capacitance and inductance. For this purpose, capacitive and inductive sensors were used, which provided a high probability of detecting a violation ($P \geq 0{,}95$) and were less dependent on the maintenance of the alarm barrier. The "Okean" was also different in appearance: its supports were metal; the alarm fence was a thin woven mesh fixed to new type insulators; all line equipment was placed in metal sectional cabinets (instead of line blocks and junction boxes in S-175).

However, the "Okean" also had significant drawbacks that were revealed during its operation. The main one, in the authors' opinion, was related to the high voltage in the communication line (380 V AC), which sometimes led to fatalities of the service personnel. Another disadvantage was the low noise immunity of the complex, due to its increased sensitivity to the effects of animals, birds and large insects.

As a result, the "Okean" system was discontinued and thus it lost its wide use, although the state border of independent Ukraine was partially guarded with this perimeter alarm system in the early 2000s.

Since 1984, the Border Guard Troops have been using the KS-185 "Gobi", the more advanced signalling complex of various modifications to ensure long-range protection for the state border. Therefore, at the time of Ukraine’s independence, some sections of its western border were already equipped with KS-185, although the countries perimeter was mostly secured with the S-175 electric signal fence. Today, the linear part of the KS-185 complex that remains on the state border of Ukraine is used only as a wire fence (Figure 5).

Figure 5 – The linear part of the KS-185 complex

Despite the fact that the KS-185 system was technically more advanced than the S-175, its information capability remained at about the same level.

The KS-185 consisted of the "Gobi-093" data collection and processing system; the object detection equipment had alarm sensors.

The KS-185 was represented in five versions based on the type of basic alarm sensors:

1) KS-185 K, the electrocontact type with the "Biriusa" alarm sensor;
2) KS-185 I, the inductive type with the "Gobi-05" alarm sensor;
3) KS-185 V, the vibration type with the "Aral" alarm sensor;
4) KS-185 EK is equipped with the capacitive type alarm sensor "Atlas" and the electrical contact type alarm sensor "Akord";
5) KS-185 EI has the capacitive type alarm detector "Atlas" and the inductive type alarm detector "Argon".

The equipment of the S-185 complex performed the following operations:

– emitting an acoustic signal of a variable tone in case alarm sensors are triggered or an attempt of unauthorised unlocking occurs;
– activating light indication on the information processing unit of the section numbers, sensor numbers, gate sensors and locking device numbers from which signals are received;
– ensuring remote control of locking devices and indication of unlocked locking device numbers on the gate (Figure 6);
– enabling automatic light indication on the information board of the four sections from which signals were received first;
– displaying indicators on the monitor of the information processing unit as for the current time and the time the incoming alarm signal was registered;
– disconnecting any number of sections and their indication on the display of the information processing unit;
– emitting an "alarm" signal and voice commands from the consoles of the head and duty officer of the border guard unit;
– monitoring the performance of the information processing unit and its display.

Until 1994, production ties with the former ussr republics were still in place, so the manufacturing plants that produced signalling equipment for the protection of long sections continued to manufacture and supply them and fulfilling their five-year production plans. Ukraine received the last KS-185 ES (a capacitive, electrocontact system) in December 1993 and put it into operation at the Lviv border guard detachment in 1995.

Figure 6 – Locking device on the gate of the linear part of the KS-185 "Gobi" signalling complex

To evaluate and compare the alarm devices for long-range protection used to safeguard the state border of Ukraine in the period of 1955 to 2000, their tactical and technical characteristics (TTC) are presented in Table 1.

Table 1 – Tactical and technical characteristics of alarm systems and long-range security systems

TTC parameter	TTC designation			
	S-100 "Skala"	S-175 "Gardina"	KS "Okean"	KS-185 "Gobi"
Length of the protected area (border), km	max 10	max 20	max 20	max 20
Number of linear sections, pcs.	max 20	max 40	max 40	max 40
Number of gates, pcs.	–	max 4	–	max 4
Length of the linear section, m	max 500	max 500	max 500	max 650 (for KS-185K); max 500 (for other versions)
Type of linear area detector	Electrocontact	Electrocontact, vibroseismic, anti-collapse	capacitive, inductive	Electrocontact ("Biriusa", "Akord"); inductive ("Gobi-05", "Argon"); capacitive ("Atlas"); vibroseismic ("Aral")
Type of gate alarm sensors	–	Vibration ("Tangens"); vibration ("Gavot") for culvert grates	–	Inductive ("Gobi-08", "Argon"); capacitive ("Atlas"); vibration ("Aral"); electocontact ("Akord")
Height of the electric alarm fence, m	2.5	2.5	2.5	2.1 (for the KS-185K); 2.4 (for other versions)
Probability of detecting a breach	0.7	0.7 (when using only an electrical contact sensor on a linear section); 0.9–0.95 (when using all types of sensors on the linear section that could be used in the S-175)	0.95	0.7 (for the KS-185K); 0.95 (for other versions)
Power supply, V	24 (alkaline batteries NK 55 or NKN 60)	220 (industrial network); 22–28 (alkaline batteries NK 80 or NK 100)	380 (industrial network)	220 (industrial network); 24 (alkaline batteries 5NK 80×4)
Continuous operation time from one set of rechargeable batteries without recharging, hrs	max 15 days	38	–	38

Until 1998, the Ukrainian state maintained the previously installed alarm systems and long-range security complexes in good working order, using the production capabilities of the OJSC "OEZ-20CA" (Kyiv). Thus, in 1992–1998, this enterprise carried out maintenance and overhaul of the S-175, KS-185, SS-84 "Vitim" radars as well as "Atlas", "Akord", "Argon", "Aral", "Biriusa", "Gobi-05", "Gobi-08", "Gavot", and "Tantal" alarm sensors.

However, in the context of European integration processes in 1998, the government decided to dismantle the signalling fences on the western section of Ukraine's border. Thus, in 1999–2000, OJSC "OEZ-20CA" dismantled almost all the equipment (station equipment, line blocks, etc.), repaired it and handed it over to the State Enterprise "Ukroboronservice" for further sale to Turkmenistan as payment for natural gas. However, some of the equipment not required by Turkmenistan was left in operation. Therefore, as an exception, some S-175 systems are still in operation on the state border with the Slovak Republic.

As of today, the signalling equipment produced by the ussr is no longer used for its intended purpose on the vast majority of sections of the state border of Ukraine.

Conclusions

Among the various types of technical systems used for protection of the state border (relatively simple common optical devices such as binoculars and telescopes to more complex ones such as searchlights and radar stations, optoelectronic surveillance equipment), in the second half of the twentieth century, alarm systems were actively used to provide long-range protection for the state border of the Ukrainian SSR and on the sections between Ukraine and with Western states. Such equipment included signalling complexes to ensure protection at long sections such as S-100 "Skala", S-175 "Gardina", KS "Ocean", KS-185 "Gobi", SS-84 "Vitim".

Alarm systems for the long-range protection of the state border played a significant role in driving modern border security and advancement in direct border protection and demonstrating the evolution of technologies in this area. However, in the world of modern technological achievements, these means are significantly giving way to more informative and effective means: integrated video surveillance systems, unmanned aerial vehicles, space monitoring equipment and other high-precision sensors that significantly improve the quality of control over the state border, providing more prompt and reliable data on the state of the area of responsibility.

A possible direction for further research could be a retrospective review of the use of signalling devices for the protection of local sections of the state border in Ukraine in the period 1955 to 2000.

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СИГНАЛІЗАЦІЙНІ ЗАСОБИ ОХОРОНИ ПРОТЯЖНИХ ДІЛЯНОК ДЕРЖАВНОГО КОРДОНУ: РЕТРОСПЕКТИВНИЙ ОГЛЯД ЗАСТОСУВАННЯ НА УКРАЇНСЬКИХ ТЕРЕНАХ У ПЕРІОД 1955–2000 рр.

Здійснено ретроспективний огляд сигналізаційних засобів охорони протяжних ділянок державного кордону, які використовували на українських теренах у період 1955–2000 рр. Під час дослідження особливу увагу приділено сигналізаційним системам і комплексам, застосовуваним в охороні державного кордону в часи Холодної війни і в пострадянський період, зокрема системам С-100 «Скала», С-175 «Гардина» і комплексам КС «Океан», КС-185 «Гоби». Описано й оцінено їх тактико-технічні характеристики, недоліки та переваги.

Для досягнення мети дослідження було вибрано ретроспективний і технічний аналіз.

На широке запровадження сигналізаційних систем для охорони протяжних ділянок вплинула Холодна війна, що характеризувалась ідеологічною ізоляцію срср і країн Варшавського договору від країн демократичного світу.

Проаналізовано еволюційні зміни в сигналізаційних засобах охорони протяжних ділянок у зазначений період. Ідеться як про конструктивне виконання, так і функціонування сигналізаційних датчиків цих засобів на різних фізичних принципах: від датчиків електроконтактного типу, де здійснювалася реєстрація зміни електричного опору, до датчиків ємнісного та індуктивного типу, де вже відбувалася реєстрація зміни електричної ємності та індуктивності.

В історичному контексті приділено увагу особливостям застосування успадкованих після розпаду срср сигналізаційних комплексів охорони протяжних ділянок державного кордону між Україною та західними суміжними державами.

Здійснено також оцінювання інформаційної здатності сигналізаційних засобів охорони протяжних ділянок.

Результати дослідження свідчать про важливість сигналізаційних засобів охорони протяжних ділянок для забезпечення безпеки державних кордонів у минулому та висвітлюють еволюцію технічних рішень, що використовувались у цій сфері. Визначаються також перспективи використання сучасних технічних рішень для підвищення ефективності контролю за кордоном у майбутньому.

Ключові слова: *державний кордон, охорона протяжних ділянок, ретроспективний огляд, сигналізаційний засіб, сигналізаційний комплекс, сигналізаційна система.*

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