Section: FUNCTIONAL AND MECHATRIC ELEMENTS OF TECHNOLOGICAL COMPLEXES

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Bezvesilna O., DThSc., Prof

Tsiruk V., PhD student

Chepuk L., PhD student

National Technical University of Ukraine «Igor Sikorsky Kyiv Politechnic Institute» / Ukraine

THE ANALYTICAL REVIEW OF EXISTING INSTRUMENTAL STABILIZING COMPLEXES

Abstract: *Instrumental stabilizing complexes are applied in modernization of existed and developing of the new light armoured vehicles (Armored Personnel Carrier, Infantry Combat Vehicle, Airborne Combat Vehicle etc.). They are intended for stabilized aiming and tracking in horizontal and vertical planes of ground, airborne and waterborne targets for effective firing from place position, in the movement and floating position. The analytical review of existing instrumental stabilizing complexes (including modes of operation, distinctive characteristics, comprehensiveness, physical and operational characteristics), developed in Ukraine, is given.*

Keywords**:** *instrumental complex, stabilization, sensing element.*

INTRODUCTION, PROBLEM STATEMENT

The acceleration of search and determination the coordinates of movable objects (MO) in extreme conditions; ground, airborne and waterborne targets observations require the establishment of a highly accurate instrumental stabilizing complexes (ISC) of MO.

Existing elements, devices, and means of well-known ISC provides minor detection and localization distances of MO. As the result of insufficient accuracy, small range of control speed, and deficiency in noise immunity the ISC's accuracy characteristics of MO are limited [2-4, 8-10].

These reasons cause the need of new ISC establishment using modern element base, that would provide high-precision directing and stabilizing the line of viewing; and working capacity under the destabilizing environmental factors and wide range of high-frequency MO.

There are no analytical reviews of existing instrumental stabilizing complexes, developed in Ukraine, outlining their physical and operational characteristics and packaging in known literature [1-10 etc.].

In that regard, the analytical review of existent ISC should be undertaken.

LITERARY ANALYSIS

Controllable sensing elements of ISC, located in MO, have been influenced by external mechanical disturbances along the three axes resulting from dynamics of MO, vibrations in driven gear of carrier, wind impact, eccentric moving elements.

The task of ISC control is resolved by using the theory of aiming and stabilizing systems [2-4]. Theory of designing the aiming and stabilizing systems was elaborated by famous scientists: A.A. Babaiev, V.A. Besekerskyi, B.A. Bulhakov; theory of linear and nonlinear aiming systems was developed by V.I. Kostiuk, A.A. Voronov, V.V. Solodovnikov, B.K. Chemodanov, N.A. Lakota; theory of digital gearing trankers was elaborated by Besekerskyi V.A., Fedorov S.M.; theory of gyroscopic systems of stabilization is developed by Pavlovskyi M.A., Pelpor D.Z., Odyntsov A.O., Samotokin B.B., Bublyk H.F., Zbrutskyi O.V., Ryzhlov L.M., Dovhopolym A.S., Bezvesilna O.M., Bondar P.M., Hrammer R., Ryvkin S.S., Roitenberh Y.N., Fabrykant Y.A., Sadovyi P.I.; theory of optimal control systems was elaborated by Bellman R., Boltianskyi V.H., Hostovyi V.I., Yeskovyi D.I. etc. [2-4].

The following organizations are considered to be the best in the field of ISC light armoured vehicles creation in Ukraine: PJSC "RPA "Kyiv automatic plant", The research and production complex "Photoprylad" (Cherkasy). Abroad, the development and research of ISC is undertaken by Russia: Krasnogorskiy zavod, Novosibirsk's optical association ("Irtysh" product) [2-4]. The designing of ISC involving the use of optical electronic systems is undertaken by firms in USA, France, Germany, Sweden, Japan, such as: International Laser Systems, USA (Northrop Grummen, Aeronitronix Ford), Sounder Associates, CBS Zabs, Perhin-Elmer, Resalab, Martin-Marietta, Rochwell-International, RCA, Texas Instruments, Naval Air Development, IBM, Filco-Ford, Thomson CSF, Hughes, Bell etc.[2-4].

As a result of analysis the native and foreign sources was detected a tendency of increasing the detection and identification distances of MO during the day: 5000 - 20000 m (for existent SC this value is 3000 -5000 m) and throughout the night: up to 5000-8000 m (for existent SC this value is 1500 -2500 m) on the ground. This requires the significant improvements of ISC's technical characteristics: aiming error not more than 1 arc minute (for existent ISC this value is not less than 3 arc minutes), increasing the accuracy of stabilizing the line of viewing (value of error is not more than 20 arc sec; for excited ISC the value of error is not less than 60 arc sec); increasing of the maximum aiming speed up to 40 per sec^{-1} (for existent- up to 35 per sec^{-1}); providing the value of minimal speed not more than 0.01 per sec^{-1} (for existent 0.05 per sec^{-1}) [2-4].

However, there is no literature that contains the solved task of analytical review of instrumental stabilizing complexes with identifying their main characteristics (accuracy, speed, enhanced functionality, cost minimization).

The purpose of this article is to undertake the analytical review of ISC with main characteristics identified.

MAIN ARTICLE

PJSC "RPA "Kyiv automatic plant" (KZA) is considered to be the main organization in the field of ISC development and research. This organization is the leading one in production and implementation of ISC into light armoured vehicles (LAV) in Ukraine and worldwide. Therefore, this article will provide information about the history of the development and implementation of ISC in LAV by KAP [1-7].

PJSC "RPA "Kyiv automatic plant" had begun the process of developing of ISC LAV in 1999, by joining to the works on creation the infantry combat vehicle BMP-1M according to technical specifications by Ministry of Defence of Ukraine ("Blindazh" theme) [1-4]. Vehicle BMP-1M was planned to supply the Ukrainian ground forces of the ministry of defence of Ukraine and to be exported abroad.

The advantages of BMP-1M over produced by Russian Federation (RF) analogues, such as: BMP-1, BMP-2, BMD, BMP-3) was concluded in larger range of weapons in the vehicles (antitank missiles PTUR and grenade launcher AG-17 were added into the weapon unit), and reduced cost. This created the real prospects for supplying to abroad clients the competitive LAV made in Ukraine [1-4].

To control the firing of all types of weapons in BMP-1M the ISC SVU-500 was used. This ISC was designed by PJSC "RPA "Kyiv automatic plant" in 1999, according to technical specification of State scientific and technical center "Artillery and rifle arming"[1-4].

The main tasks of developing SVU-500 [1-4] was:

- creation the native ISC LAV, because the purchasing of abroad vehicles (for example weapon stabilizer 2E36 of BMP-2 produced by RF) can't ensure the autonomy of ISC production in Ukraine.
- decreasing the overall mass and dimensions comparing to the serial ISC 2E36 of BMP-2, since the diameter of weapon unit in modernized BMP-1 is 1,5 times less than BMP-2;
- significant decreasing of price, comparing to the ISC 2E36-1 (production of RF).

All assigned tasks were fully implemented while creation of the first native ISC SVU-500, that have the following advantages comparing to ISC 2E36-1 of BMP-2 [1-4]:

- the overall mass of SVU-500 was reduced to 90kg (comparing to 120 kg in 2E36-1) with corresponding decrease of main blocks dimensions;
- increasing of the maximum aiming speed up to 35 deg per sec (for ISC 2E36-1 this value is 30 deg per sec);
- introduced the PTUR mode with decreased minimum tracking speed up to 0.02 deg per sec (there is no such mode in 2E36-1);
- the price of SVU-500 is reduced by 2.5 times comparing to 2E36-1 (taking into account customs clearance).

Taking into account the significant improvement of technical and economical characteristics of native ISC SVU-500 for LAV (comparing to ISC of models 2E36-1, 2E36-3, 2E36-4 i 2E36-5 made by USSR and RF), the decision were made to apply ISC SVU-500 in the new models of LAV, such as BTR-3E, BTR-3E1, BTR-

3C, BTR-4, that are in process of developing by defense industry of Ukraine, and into LAV, that serves to the Ukrainian ground forces (BMP-2 and BTR-80)[1-4].

The works on creations of ISC SVU-500 for different types LAV were help at stages [1-7]:

1. In 1999 the materials were developed for submission to competition in order to obtain designing and manufacturing rights to create the first native unified ISC LAV.

PJSC "RPA "Kyiv automatic plant" was preferred in the competition, that was managed by the head of Main armored bureu MDU, because of its great experience in elaborating the design documentations and production of ISC units for BMP-2.

In the third quarter of 1999 in conjunction with the State scientific and technical centre “Artillery and rifle arming” (ACO-2) were developed and approved the “Technical task of developing the part of experimental design work (EDW) “Elaboration of weapon stabilizer” (pressmark “Karusel”).

In the fourth quarter of 1999 within the shortest possible period of time was developed the design documentations that consisted of all units of ISC SVU-500 and inspection testing equipment. The elaboration and supply the 2 sets of ISC SVU-500 to State scientific and technical centre “Artillery and rifle arming” (ACO-2) for joint rehearses as a part of weapon unit “Shkval” of modernized BMP-1M [1-7];

2. In 2000-2001 10 sets of ISC SVU-500 were elaborated and supplied for modernization of LAV BMP-1M, that was successfully demonstrated during the military parade, dedicated to 10^{th} anniversary of Independence of Ukraine[1-7];

The successful preliminary tests of BMP-1M was held in the territory of Zhytomyr repair mechanical factory (ZRMF) within the shooting gallery and testing ground from 20.08.2001 to 25.10.2001.

Certificate of preliminary tests of BMP-1M prototype was approved by head designer on 25.10.2001.

Also preliminary tests of BMP-1M with ISC SVU-500 was held in the territory of Horcharivsk testing ground MDU within Chernihiv region using the great number of shoots from automatic cannon, tank machine gun PKT and automatic machine gun for firing from place and movement position at targets located from 100 m up to 4000 m.

3. In 2002, following the recommendations of the BMP-1M upgraded testing commission and to improve the reliability and ergonomic performance of the fire control system, documentation on the ISC SVU-500 was corrected by introducing the laser rangefinder controls directly on the fire control panels, as well as the introduction of integral protection of electric drives for guidance from current overloads [1-7].

In addition, in 2002, an original source of secondary power supply was developed - a static three-phase converter SP10 of the primary supply of the 27V overhead line to a 36V sinusoidal voltage variable [1-7]. The development was carried out with the aim of replacing the electric transformer PT200TS-III, the production of which was terminated in Russia, and in Ukraine, such converters were not produced at all.

In order to concentrate the process of serial production of ISC equipment in the same enterprise in a single closed loop without supply of units in cooperation with other enterprises, an electric motor was developed with an inertial EDM20M [1-7].

For the production of ISC for serial production, design documentation for the SVU-500 and input blocks, the company's commission was checked for compliance with GOST 2.902-68 and prepared for presentation to the State Commission. The Commission approved the documentation on ISC SVU-500 for serial production by approving the decision of 6.06.2003 with the assignment of the letter O1 "[1-7].

During 2004-2006, more than 100 sets of ISC SVU-500 for Shkval combat modules BTR-3E made and delivered to foreign customers (Myanmar) were manufactured and delivered to Zhytomyr RMZ [1-4];

4. Taking into account the current trends in improving the tactical and technical characteristics of the LAV and in order to maintain the competitiveness of the domestic LAV in the international arms market, in 2006, KZA began to create promising ISCs based on the digital principles of controlling the movement of the stabilization facility - the armament block and the tower of the car. In this case, the main blocks of the ISC (control panels and control units) are developed on a digital element base of high degree of integration, which reduced the size of blocks and the mass of ISC by more than 20%, improve reliability and improve the ergonomic performance of the entire fire control system. The stabilizers have SVU-500-3D indices for Shkval combat modules BTR-3E and BMP-1M, SVU-500-4D for Shturm-M combat modules BTR-3E1 and SVU500-4D-01 for combat modules "Parus" machine BTR-4 [1-7].

Samples of digital stabilizers are subjected to a comprehensive exhaust test for each block as well as ISC in general on a special stand and as part of the real tower of the machine BMP-2.

In addition, the digital ISC was installed in the product BTR-3E at the enterprise ZPVM KP with the conduct of standard tests. Test results are positive. The joint decision No. 63050 KD on digital ISC SVU-500-3D and SVU-500-4D has been approved for serial production [1-7].

The BTR-4 combat vehicle with the SVU-500-4D-01 stabilizer successfully passed the State Test and was accepted into the MDU Army [1-4].

5. Despite the high technical and economic performance of the ISC SVU-500, especially the digital versions, the lack of these products in terms of perspective development is the use of sensitive elements of electromechanical gyroscopes that have insufficient accuracy and resource, limited resource of ball bearing suspensions rotor gyroscope. In addition, for the power supply of the hygrometers, a special source of alternating voltage of sinusoidal shape is required. These disadvantages increase the cost of the equipment and do not allow to significantly improve the accuracy of the stabilization, resource and reliability of the fire control system of modern LAV [1-7].

In this regard, and in order to maintain the promise of the digital ISC of the SVU-500 series, it was decided to replace electromechanical gyroscopes with solid-state coriolis gyroscopes (CVGs) [1-7].

ISCs with CVG gyros have indexes that determine their applicability in specific types of LAVs, namely [1-7]:

- SVU-500-7D for installation in the product BMP-2, (instead of obsolete stabilizers 2E36);
- SVU-500-7D.01 for installation in the product BTR-80 (there were only manual non-stabilized drives);
- SVU-500-7D.03 for installation in the product BTR-3E1, instead of SVU-500-4D at the conclusion of new contracts for deliveries to foreign customers;
- SVU-500-7D-04 for installation in the product BTR-4E instead of SVU-500-4D-01 for supplies to the MDU troops and foreign customers.

The following technical requirements have been developed for the development of these ISCs [1-4]:

- "Tactical and technical task for the development of ISC SVU-500-7D for LAV (BMP-2 and BTR-80)", approved by the Department of Development and Procurement MDU and agreed with the heads of units MDU;
- "Technical task for the development of the DKR" Modernization of digital stabilizers for easy armored combat vehicles based on modern sensitive elements ", approved by the Deputy Director General of the State Concern" Ukroboronprom".

At PJSC "RPA" Kyiv automatic plant "together with scientists of the instrument-making department of the KPI named after Igor Sikorsky and Zhytomyr State Technological University, the research of perspective types of sensitive elements of ISC is conducted: gyroscopic [8-10], piezoelectric [11-12], strings vibrational [13-14], capacitive [15-16].

The PSC "RPA" Kyiv automatic plant "developed the studied ISC SVU-500-7D (Fig. 1) for BTR-4E (Fig. 2).

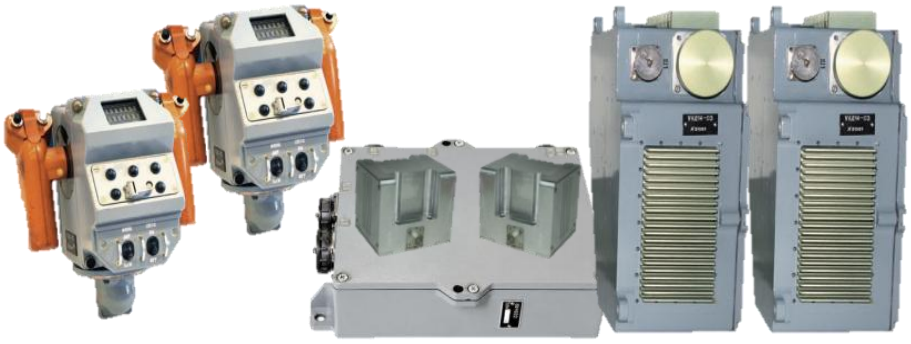

Fig. 1. *Scheme of interaction of streams of IFMS, authors':*
M – material flow, E – energetic, I_1 – management information, I_2 – organization of information functioning of IFMS, W- ware [1-2]

Fig. 2. *Scheme of interaction of streams of IFMS, authors':*
M – material flow, E – energetic, I_1 – management information, I_2 – organization of information functioning of IFMS, W- ware [1-4,17-19]

According to special press, Ukrainian weapon stabilizers are considered to be one of the best is Europe [17-19]. PJSC "RPA "Kyiv automatic plant" produce one of the most reliable and flawless ISC for LAV [17-19].

ISC included in: "Shkval" fighting module for BTR-3E armored personnel carrier, and BMP-1M infantry combat vehicle (SVU-50-3D), "Shturm" weapon station and "Parus"weapon station for BTR-3E-1 and BTR-4E (SVU-500-4D-01) [1-19].

The basic information about specified ISC is given [1-4].

Modernized digital complexes ISC SVU-500-3D ЮКАИ.461314.001-03, SVU-500-4D ЮКАИ.461314.001-04 and SVU-500-4D-01 ЮКАИ.461314.001-05

Purpose and usage of ISC:

ISC can be used for modernization and designed new lightly armored vehicles: armored personnel carrier, infantry combat vehicle, airborne combat vehicle etc. Stabilization complexes are intended for stabilized aiming and tracking in horizontal and vertical planes of ground, airborne and waterborne targets for effective firing from place position, in the movement and floating position [1-4].

Working modes of ISC [1-4]:

- Automatic – to shoot by ground and waterborne targets;
- Semi-automatic – to shoot by airborne and highly maneuverable ground targets;
- Control – to shoot by antitank guided missiles;
- Targeting – re-aiming by the commander order;
- Readiness – setting of powerful armament into starting position;
- Ready – mode for reducing the readiness time from 2 minutes to t ≤ 1sec;
- Diagnostics – auto diagnostics of working correctness of basic units during the working regimes;

- Up and down - round the elements of the design of products BTR, BMP, preventing the turn of the tower and armament.

The ISC complex provides [1-4]:

• rapid target reallocation, selected by the commander;

• installation modes on the charging corners;

• bringing the armament and tower to the starting position.

Distinctive features [1-4]:

The latest ISCs SVU-500-ZD and SVU-500-4Ds differ from the ISC SVU-500, 2E36 and 2E52 LAV by implementing the laws governing the movement of weapons and the modes of digital operation on a modern elemental base and the exchange of information between digital control units and remote controls. The firing management is based on the interruptible digital interface developed by KZA [1-4].

Adjustment of ISC parameters is carried out by the operator from the shooting control panel without manipulation of the control elements on the control units. Information about the ISC's operating and service modes is displayed on the digital display of the control panel alphabetically and numerically [1-4].

Due to the optimization of circuit-engineering decisions and control laws, the instrumentation (the compensating gyro tahometer and a separate block of filters are excluded) are reduced and mass [1-4] is reduced.

Complete set [1-4]:

The complete set of ISC SVU-500-3D includes:

- 2 pcs. gyro tachometers (GT46 on vertical channel and GT46-01 on horizontal channel);

Digital control unit BU1022-04;

- 2 pcs. power amplifiers UUD14-02;
- 2 pcs. electro motors EDM-20M;
- Digital control console of firing PU03-05;
- Target designation device for commander PTsU01-01;
- Static power adapter SP10-01;
- 2 pcs. Angular sensors DU-04 armament tuning in horizontal and vertical planes;
- Cable complete set of the link between units.

ISC SVU-500-4D [1-4]

The stabilizer composition SVU-500-4D is differ from stabilizer SVU-500-3D by availability second control console of firing for commander and absence of device PTsU01-01, since the targeting mode is conducted by the panoramic viewer (is not a part of SVU-500-4D) [1-4].

Basic technical characteristics [1-4]:

Range of angular guidance:

- in horizontal plane – cycling rotation;

- in vertical plane – from minus 6 deg to plus 60 deg;

Drive power of vertical and horizontal guidance – 500 W.

Rate guidance in horizontal and vertical planes:

Maximal:

- in semi-automatic mode - not more than 35 deg/sec;

- in automatic mode - not more than 6 deg/sec;
- in control mode – not more than 0.5 deg/sec.

Minimal:

- in semi-automatic mode - not more than 0.1 deg/sec;
- in automatic mode - not more than 0.07 deg/sec;
- in control mode – not more than 0.02 deg/sec.

Mean error of stabilization, distance parts per thousand (angular minutes) – not more than 1 (3.6).

Statical error in modes:

- Non-fluency during the small speed – not more than 0.3.

Life time:

- guarantee – 7 years;
- general – 20 years.

Mass:

- SVU-500-3D not more than 65 kg;
- SVU-500-4D not more than 68 kg.

Average error of stabilization, exact readings, (angular minutes) – not more than 0.7 (2.5).

Non – smoothness of guidance at low rates, exact readings – not more than 0.7.

Fig.3. *Digital weapon stabilizer SVU-500-10P [1-4]*

Designed for guiding in the horizontal and vertical planes of the BTR armament during the firing of ground and air targets [1-4].

Table 1

Technical characteristics

Readiness time, sec, not more than	2
Non-fluency speed of aiming, not more than	1
Maximal speed of aiming in vertical and horizontal planes, deg/sec, not less than	25
Minimal speed of aiming in vertical and horizontal planes, deg/sec, not more than	0,07
Angles of aiming, deg, in planes: horizontal vertical	 n×360 -5 до +45

Digital Stabilizer SVU-500-7D [1-4]

The new ISC, developed, investigated on KZA and installed on the machine BTR-3E1 is an ISC, consisting of a gyrostabilized platform, a vibration damping system, and a CVG sensitive element. The development and research of CVG was initiated by the Arsenal State-owned enterprise of special instrument-making. In view of CVG's promise, a package of design documentation and new CVG modifications [patents of Ukraine 5-7] was developed at PJSC "RPA" KYIV AUTOMATIC PLANT ", comprehensive CVG studies in the part of ISC SVU-500-7D-03, which were installed on the BTR military vehicle, are being carried out. -3E1 [1-7].

12.12.2013 PJSC «RPA« KYIV AUTOMATIC PLANT »(the state shareholding of which is under the management of DK" Ukroboronprom ") presented a new development of the enterprise - digital ISC SVU-500-7D. CVG was used as a sensitive element in ISC. The use of a modern element base has made it possible to significantly improve the technical characteristics of the entire system [1-7].

Subsequently, the ISC LAV has indices that determine their applicability in specific LAV types, namely [1-4]:

- SVU-500-7D for installation in the product BMP-2, located in the army MDU;
- SVU-500-7D-01 for installation in the product BTR-80, which is in the army in the MDU (BTR-80 at this time, have only manual non-stabilized drives);
- SVU-500-7D-03 for installation in the product BTR-3E1, instead of SVU-500-4D at the conclusion of new contracts for deliveries to foreign customers;
- SVU-500-7D-04 for installation in the product BTR-4E instead of SVU-500-4D-01 for supplies to the MDU troops and foreign customers.

CONCLUSIONS

From an analytical review of existing instrumentation stabilization complexes:

1. The SVU-500 stabilizer is designed and implemented for stabilized guidance in horizontal and vertical planes of RA during firing from the course, from place to place and for swimming for ground and air purposes [1-4]. The composition, main modes, technical characteristics, work of this ISC are outlined. The modernization of the ISC SVU-500 was carried out in stages by the use of new perspective components of the element base and information sensors [1-4];

2. Given the present and future demand for LAV and to maintain the competitiveness of these products on the international market, PJSC "NVO" KZA "since 2006 has carried out a radical upgrade of ISC SVU-500 with the development of new variants ISC SVU-500-3D, SVU-500 -4D and SVU-500-4D-01. These ISCs have fundamental differences from their predecessors SVU-500 [1-7]:

- digital controllers are used in control units (BU) and control panels (PU);
- a visual litter - digital display on the special digital display on operating modes and basic parameters of the ISC is introduced in the control panels;
- The ISC setup in the LAV is performed by one operator directly from the control panel (in the SVU-500 the adjustment is made by the control potentiometers installed in the niches of the control units located in an inaccessible place);

- algorithms of the integral protection of electric motors against overload and the task of forming pulse-width (PWM) signals transferred from power amplifiers to the digital part of the control unit;

- In the amount of released power amplifiers, elements from the filter block were introduced, resulting in a separate block of filter BF03 was excluded from the digital stabilizers;

- from the control circuits leading the block of armament on the vertical channel excluded compensating giotahometer and electromagnetic tachometer by introducing in the digital algorithms of the microcontroller special correction units;

- in the digital control unit algorithms for automatic diagnostics of the working state of the stabilizer units are implemented, which facilitate the operation of the caretakers in search of and elimination of possible malfunctions;

- reduced immobility of the movement at small driving speeds from 1 ton to 0,8 tons;

- increased stability of the blocks of the stabilizer to the climatic destabilizing factors - operating temperature increased from + 50 ° C to + 60 ° C, relative humidity up to 100% at + 35 ° C, resistant to the influence of mold fungi;

- the mass of digital stabilizers SVU-500-4D is reduced to 70 kg, in comparison with 90 kg in SVU-500 [1-4].

3. A promising SVU-500-7D high-precision stabilizer has been developed on new promising sensitive elements - CVGs, in which the bandwidth is expanded to 100 Hz or more [1-7]. CVG development and research was launched at Arsenal Central Design Bureau under the direction of MI. Lycolida Taking into account the promising use of CVG, at the PJSC "NVO" KZA, CD development, CVG manufacturing and comprehensive tests, including the stabilizers SVU-500-7D and BTR3E1 [1-7], have been carried out. The novelty of some technical decisions regarding CVG is confirmed by the patents of Ukraine [5-7];

4. On the basis of the research work, the technical design of the modernized instrumentation complex of the stabilizer of increased accuracy and reliability of SVU-500-7D was determined, which differs from the serially manufactured by now improved characteristics [1-7].

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