https://doi.org/10.15407/knit2021.04.083
UDC 681.3 (09)

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THE CONTRIBUTION OF KHARKIV ENTERPRISES TO THE ROCKET AND SPACE INDUSTRY DEVELOPMENT

The article reviews the contribution of Ukrainian enterprises to the development of the rocket and space industry. The most important part of a space or combat ballistic missile is the control system (CS), on which the success of its application depends. Kharkov (Kharkiv) enterprises – the "Kommunar" plant and the Design Bureau "Electropriborostroenia" (SDB-692, now the RPA "Khartron") were the largest manufacturers of control systems not only in Ukraine but throughout the Soviet Union. These systems were not only produced serially but also developed at these enterprises. The formation and development of Kharkov enterprises of the space industry is the most important page in the history of the development of not only cosmonautics but also science and technology. Despite the large number of works devoted to the development of rocket and space technology in Ukraine, the history of the development and production of control systems has not been sufficiently studied. Due to the secrecy of work in the field of rocket and space technology (RST), there are very few sources for studying the history of its creation. Therefore, the most important part of the work was interviewing the leading experts of SDB-692 in the field of the rocket and spacecraft control systems, which included A. M. Kalnoguz, Yu. A. Kuznetsov, V. Ya. Makarenko, V. G. Sukhorebrov and V. A. Uralov. Based on these interviews, a special fund was created in the Central State Scientific and Technical Archive of Ukraine. Control systems for many combat ballistic missiles, including P-7, P-7A, P-12, P-16, as well as the most powerful missile in the world P-36M2, which was named in the USA "Satana" (SS-18 "Satan"), "Proton", "Zenith", "Energia", and "Cyclone" launch vehicles, "Kvant", "Kvant-2", "Crystal", "Priroda", "Spectrum" orbital modules, more than 150 satellites of the "Cosmos" series, and other objects were developed and serially produced at Kharkov enterprises. In the 1970s, SDB-692 created the USSR's first onboard digital electronic computer. On its basis, a test and launch complex "Electronic launch" was developed, designed for pre-launch testing of control systems for ballistic missiles and launch vehicles.

Keywords: *space industry, launch vehicle, spacecraft, combat ballistic missiles, control systems, the "Kommunar" plant, DB "Electropriborostroeniya", Kharkiv Polytechnic Institute.*

Цитування*:* Larin A. A., Gutnyk M. V., Tkachenko S. S., Horielova S. O. The contribution of Kharkiv enterprises to the rocket and space industry development. *Space Science and Technology*. 2021. **27**, № 4 (131). С. 83—90. https://doi.org/10.15407/knit2021.04.083

Introduction. The development of rocket and space technology, the exploration of near-Earth space are the characteristic expressions of human society's current evolution. At the same time, today, astronautics itself acts as a kind of synthesis of what has been achieved by world science and technology. The progress and creation of the rocket and space systems operated in space, artificial Earth satellites, manned spacecraft, and interplanetary automatic stations accelerated the development of some scientific and technical fields that were not previously associated directly with space.

Cosmonautics, with its unprecedentedly high requirements for the reliability of systems and equipment, today encourages the industry to catch up to a level that was not above it the day before, makes it use the latest achievements of science and technology to improve and modernize production. The level of the modern rocket and space technology is associated with the introduction of the latest achievements of the scientific and technological revolution into production, and each of them, in turn, is enriched as a result of the use of scientific achievements in the study of processes and phenomena occurring in outer space.

Ukraine is one of the few countries in the world where launch vehicles, spacecraft, and combat ballistic missiles are created [23]. The study of the history of rocket and space technology (RST), participation in this process of the leading enterprises of Kharkiv, and above all, the "Kommunar", "Khartron" enterprises – is the most important component of the modern history of science and technology.

A considerable number of works have been devoted to the development of the Ukrainian spacecraft. From all publications, it should be mentioned the monographs devoted to the activities of the rocket spacecraft designers — M. K. Yanhel [16], V. S. Budnik [2], V. F. Utkin [22], S. M. Koniukhov [15], and Yu. S. Aleksieiev [21]. The works published to the anniversary dates of the Pivdenne State Design Bureau (PDB or SDB-692) [3, 12, 20] were devoted to its labour activity.

Research objective. The purpose of the article is to analyze the creation and activities of enterprises of rocket and space engineering in Ukraine using Kharkiv enterprises as the example.

Sources. The most important part of a space or combat ballistic missile is the control system (CS), on which the success of its application depends. The largest manufacturer of control systems in Ukraine and throughout the entire Soviet Union was Kharkiv city, where enterprises not only mass-produced these systems but also developed them. The emergence and development of the Kharkiv space industry have become the most important page in the history of the progress in astronautics and the entire science and technology in general.

However, the history of the development and production of control systems in Ukraine has not been sufficiently studied. Existing works on the history of Kharkiv enterprises [11; 17] are saturated with a large amount of information, accompanied by colorful illustrations, and are chronicles of dates and events. However, unfortunately, there is no deep analysis of the relationship between the development of enterprises and domestic and foreign science and technology as a whole. In addition, these publications were distributed mainly among the employees of these enterprises, they are not represented on the Internet, and their edition is very limited.

The activity of Kharkiv enterprises on the creation of the RST control system was covered in a collective monograph [1], but it focused only on the participation of employees and graduates from the Kharkiv Polytechnic Institute (NTU "KhPI"). Another collective monograph [19] was devoted to the life and creative career of the Chief Designer of control systems Volodymyr H. Serhieiev (1914—2009). Andrii S. Honchar (1925—2003), Chief Designer of the control system of the "Almaz" rocket and space complex of the transport supply ship, as well as the autonomous control complex of a super-heavy launch vehicle "Energia", thoroughly described the history of the creation of unique control systems for rocket and space vehicles in his memoirs [10]. He, for many years, had worked in the DB "Elektropriborostroenie" (SDB-692, since 1995 — research and production association "Khartron").

However, the memoirs of A. S. Honchar are an exception. For obvious reasons, all works on the creation of the CS were strictly classified. Taking into account this information, the work carried out by NTU "KhPI" engineer Svitlana O. Horelova is very

important and actual. She interviewed the leading employees of SDB-692, who participated in the most important work on the creation of a control system for combat missiles and spacecraft, namely Anatolii M. Kalnohuz, Yurii O. Kuznietsov, Oleksander Ya. Makarenko, Viktor H. Sukhorebrov, and Volodymyr O. Uralov. All interviews are devoted to the activities of respondents in SDO-692 in the period from 1959 to 1988 and were placed in the Central State Scientific and Technical Archive of Ukraine, where the fund 251 "Oral-historical documents on the history of science and technology" was created [4—9].

"Kommunar". The production of combat ballistic missiles in Ukraine began in 1951. The production of the P-1 rocket[1] (8A11, according to NATO classification — SS-1 "Scunner") was organized at the repurposed Pivdennyi Machine-Building Plant (plant no. 586) from the automobile one. Soon a special design bureau SDB-586 (Pivdenne design bureau) was created at the plant. Mykhailo K. Yanhel, who had previously worked as the Chief Engineer of Research Institute-88, was appointed as the Chief Designer of the SDO and Vasyl S. Budnik became his deputy. For the mass production of P-1 missile control systems, the Kharkiv plant "Elektroinstrument" was allocated. It was given a new name — plant number 897, open name — plant "Kommunar". It became the first enterprise in the USSR for the serial production of equipment for onboard autonomous control systems and ground test starting electrical equipment for missile systems. Volodymyr N. Kulikov was appointed as a Director of the plant, and Abram M. Hynzburh became its Chief Designer. Already at the initial stage, production workers faced many technical problems, which had to be solved operatively, on the spot, without waiting for help from central design offices and research institutes. Due to this, by the Decree of the USSR Council of Ministers no. 5071-2199cc of December 12, 1951, in order to "quickly master the serial production of control system equipment for the P-1 product", a special design bureau was organized at plant no. 897 from January 1, 1952 (SDB-897). This SDB-897 was headed by Abram M. Hynzburh [11, P. 18—21]. The scientist understood the role and significance of the theory and put a lot of effort into the creation of the different subdivisions.

The first important achievement of SDB-897 was its participation (together with the Research Institute-885 team, Chief Designer Mykola O. Pyliuhin) in the development of a control system for the country's first strategic medium-range missile P-12 (8K63, SS-4 "Sandal"). In this rocket, the Chief Designer of which was M. K. Yanhel, for the first time high-boiling fuel components were used, which made it possible to use a silo-based missile launch. Exactly for the P-12 rocket, a completely autonomous inertial control system was created for the first time. Before that, a radio correction system was used. For this work, a group of SDB employees was awarded government awards, and Chief Designer A. M. Hynzburh became a Lenin Prize Laureate.

The first independent development of the SDB of the "Kommunar" plant was the design of a control system for the "Oneha" powder tactical missile (1955). It was based on the principle of a "pure" inertial control. A characteristic of the system was the one-coordinate control method developed in SDO-897, implemented based on one pendulum accelerometer on the inner axis of the gyro horizon and a discrete calculating device. The control system included a pitch gyro, lateral and normal stabilization accelerometers, and pneumatic steering gears. And although the "Oneha" rocket did not go into series production, its flight design tests confirmed the correctness of the principles established in the control system construction.

As the "Kommunar" plant was the only one in the country where missile control systems were serially manufactured, in 1958, it received a task to produce onboard and ground control equipment for the P-7 (8K71) rocket. The task became fateful both for the plant and for the SDB since later modifications of the P-7 combat missile were used to launch artificial Earth satellites.

So, on October 4, 1957, the first satellite of the Earth was launched into near-Earth orbit with the P-7A (8K74) rocket, equipped with an additional block of the last stage. A month later, on November 3, the next flight took place with the dog Laika on board. The next modification of the "Seven" made it possible to deliver a pennant with the emblem of

[1] Hereinafter in the text "P" in the designation of the rocket — the first letter of the word "rocket" in Ukrainian

thse USSR to the Moon (September 12, 1959) and fly around the Moon, photographing its reverse side (October 04, 1959). On April 12, 1961, the same rocket launched the first manned spacecraft "Vostok-1" into orbit with pilot-cosmonaut Yuri Gagarin [11, P. 34—39].

In total, over 50 years, rockets equipped with onboard control system equipment manufactured at "Kommunar" and launched with the help of a ground-based test and starting electrical equipment (TSEE) manufactured there have put into near-Earth orbits more than 3,500 spacecraft for various purposes. Among them, there were more than 250 manned spacecraft or ones for providing work of astronauts at long-term orbital stations-laboratories [11, P. 114].

In 1964—1966 SDB "Kommunar" became the leader in the creation of a control system for the three-stage universal missile UR500 ("Proton"). The plant manufactures 49 devices, which make up 80 % of the total number of apparatus for the onboard control system of this missile. Since 1967, the "Proton" launch vehicle has launched into space more than 280 different spacecraft for scientific and national economic purposes, the mass of which reaches 12.5 tons. Among them, there are the well-known orbital space stations "Salyut", "Mir", modules "Kvant", "Kristall", et al. [23].

In 1969, the "Lunokhod" and "Lunokhod-2" self-propelled vehicles were delivered to the Moon by the "Proton" rocket. Scientists of the "Kommunar" plant also took part in these works as manufacturers of onboard equipment installed at the "Luna" stations, which controlled the movement, entry into low-Earth orbit, and braking of the apparatus for the Moon landing.

In the 1980s, from the modules launched into the near-Earth orbit by the "Proton", the space station-laboratory "Mir-2" weighing 130 tons was assembled, and it had been in the orbit for more than 15 years until April 2001.

In 1982, the "Kommunar" initiated manufacturing of prototypes, and in 4 years started serial production of onboard equipment for the control system of the new "Zenit" space carrier (11K77). Mastering the production of such an order became the next stage of technical progress for the plant. The "Kommunar" team became a participant in a large-scale international project called "Sea Launch", in which the rocket in variant the Zenit-3SL was used. Norway, the USA, Russia, and Ukraine were taking part in the implementation of this project. "Sea Launch" was the first in the world to be launched from a mobile offshore platform. Moving across the ocean made it possible to launch rockets from geographic points that were optimal for the assigned tasks, including the equatorial ones.

Between 1983 and 1986, the "Kommunar" manufactured and supplied strategic missile forces with a unified "Signal-A" remote control system designed for the "Topol" mobile ground-based missile system. The ground control system equipment located in a separate bunker of the self-propelled launcher was mass-produced at the Production Association "Kommunar".

Another area of the PA "Kommunar" activity was the creation of ground complexes for spacecraft testing at manufacturing plants and in operation, including pre-launch preparation. In 1966, SDB "Kommunar" received the first task to develop an automated test complex designed to operate as part of the "Almaz" space complex, created under the leadership of General Designer Volodymyr M. Chelomei. The 11N560 complex (KIK) was developed and put into production, which, in terms of its technical characteristics, operational data, and schematic design, had no domestic analogues.

During the decade (from 1970 to 1980), 18 such complexes were manufactured, which have been operating at industrial plants and at technical and launch sites of the Baikonur and Plesetsk Cosmodromes.

Since 1977, PA "Kommunar" has been creating a universal control and recording automated ground complex "Kiparis" for testing various control objects. From 1981 to 1991, the plant's staff manufactured and delivered 34 sets of this equipment to the main industrial enterprises, to the technical and launch sites of the Baikonur Cosmodrome. It provided testing of the reusable spacecraft "Buran" at all stages of preparation for the flight, which took place on November 15, 1988 [12, P. 103]. The most important reward for labor was two successful starts of the "Energia" launch vehicle, successful field tests, and the 15A18M (SS-18) rocket putting into service.

The history of the plant is formed from the fate of people who at different times worked in its team. There five Heroes of Socialist Labor, two laureates of the Lenin Prize, eleven laureates of the USSR State Prize were worked. More than a thousand employees of the enterprise were awarded government awards for their work – orders and medals, which demonstrated a significant contribution to the mastering, creation, and development of rocket and space technology.

DB "Elektropriborostroeniya". The next enterprise, which should be noted, is DB "Elektropriborostroeniya", created in 1959. The history of this enterprise began in PDB under the leadership of M. K. Yanhel with the development of a two-stage intercontinental ballistic missile (ICBM) P-16 (8K64, SS-7 "Saddler"), intended for ground launch sites. Wanting to protect the missile from interference, M. Yanhel, the Chief Designer of SDB-586, decided to equip it with an inertial CS. Not finding support from the director of Research Institute-885 M. Ryazanskiy and his deputy M. Pyliuhin, M. Yanhel appeals to the government with a proposal to organize a new design bureau for the CS development in Kharkiv. In April 1959, based on SDB-897 and SDB-285, a new special design bureau was created – SDB no. 692[2]. It was supposed to become the Head research and development enterprise, coordinating work on the creation of control systems for missiles developed in SDB-586. The core of the enterprise was the team that moved from SDB-827. Borys M. Konoplev was appointed as the Head and Chief Designer of SDB-692, and Abram M. Hynzburh became the deputy of the Chief Designer [1, P. 41]. This new design bureau became the leading one in the industry for the development of an automatic stabilization device and a complex of ground TSEE. At the first stage, Research Institute-944 (Chief Designer — Viktor I. Kuznietsov) was the Main organization for autonomous control systems, command gyroscopic devices, and automatic firing range control.

For the first time in domestic practice, it was proposed to develop an autonomous CS based on a three-axis gyro-stabilized platform with gyrointegrators installed on it in the firing plane. The control of the firing range was carried out based on one of the varieties of the functional guidance method developed by Academician Oleksandr Yu. Ishlinskyi. Its instrumental implementation was carried out by an electromechanical calculating device. The program functions on board the rocket were reproduced by electromechanical tape recorders with a special wire instead of a ferrite tape and by temporary program-current distributors.

The autonomy of control on the inertial navigation system base required high accuracy of stabilization of the mass motion center, and, in this regard, an original solution to the problem of high-precision control of the apparent velocity (CAV) was proposed. This problem was solved using lamella sensors with a relay characteristic. The traditional amplifier-converter was replaced by a relay-logic signal converter. This system provided very low static error and was characterized by increased control dynamics. A large series of ground tests on real engines, carried out at the initiative of B. Konoplev, proved the mutual compatibility of engines and the CAV system.

Simultaneously during these tests, for the first time in the country, the liquid-jet high thrust engines' dynamic as a control object was studied. The creative team of the newly established SDB-692 was the first in the country to develop onboard devices for an automatic stabilization device that had implemented complex control laws based on magnetic semiconductor elements [17, P. 22].

The P-16 missile test is associated with the largest catastrophe in the history of rocketry, which occurred on October 24, 1960. Then 78 people died, including the Chief Marshal of Artillery Mytrofan I. Nedelin, the CS Chief Designer B. Konoplev, the Deputies of the Chief Designer Vasyl A. Kontsevoi, and Lev A. Berlin, the Deputy of the Chief Engineer Heorhii F. Firsov, the Deputy Head of the landfill Colonel Oleksandr I. Nosov [14]. The accident occurred due to violations in the standard procedure for the rocket launching. As a result, there was a premature launch of the main engine second stage, which burned the bottom of the oxidizer first stage tank, and then the second stage fuel tank collapsed, which led to a powerful fire and complete missile destruction.

Despite the loss of leading specialists, work on the P-16 Control System was continued. Volodymyr H. Serhieiev became the Chief Designer of SDB-692 and

[2] SDB-692 received box number 67 (mailbox) and the official name — DB "Elektropriborostroeniya", now the Research and Production Association "Khartron".

held this post until 1986. In October 1961, according to the SDB-692 documentation, serial production of the P-16 missile control system equipment began. It became the first long-range ballistic missile (up to 13,000 km) with a short preparation time (18 minutes) and a dispersion radius of no more than 10 km.

The protected autonomous inertial control system created in SDB-692 included automatic angular stabilization, the center of mass stabilization, an apparent speed control system, a system for simultaneous emptying of tanks, and automatic range control. For the first time on the Soviet intercontinental missiles, a gyro-stabilized platform on a ball bearing suspension as a sensitive element of a control system was used. It was the creation of the P-16 control system in SDB-692 that allowed Kharkiv to declare itself not only as the largest serial manufacturer of control systems but also as a center for the development of rocket and space technology.

In the middle of the 1960s, SDB-692 was appointed as a lead organization for the development of the CS complex for the 63C1 launch vehicle. For the SDB-692 team, this was a prestigious task — by this time, the only P-7 launch vehicle had been created in the country, the control system of which was developed at Research Institute-885 under the leadership of Mykola O. Pyliuhin, who had indisputable authority in this field.

After two unsuccessful launches of the 63C1 rocket, on March 16, 1961, a successful launch was carried out, as a result of which the first satellite DS-2, developed by SCB-586 and known as "Cosmos-1", was launched into the orbit. With this launch, SCB-1 s monopoly on both the launch vehicles and the artificial Earth satellites themselves ended. For SDB-692, this was an important launch, which, together with the successful course of the P-16 rocket's flight tests, demonstrated the increased level of professionalism of its developers [17].

Several years before the SDB-692 creation, there was active growth of enterprises, which later formed its core: SDB-897 and SDB-285 of the plant named after Shevchenko. During this period, the future well-known creators of the rocket and space technology were hired: Vitalii K. Kopyl — the Head of the instrumentation department, where onboard and ground launch equipment was created; Andrii S. Honchar — Chief Designer of the "Energia" rocket control system; Sergiy S. Coruma and Venedykt D. Stadnik — high-class ballistics, whose ideas were used in the creation of missile control systems and were providing them with an incredible accuracy of hitting the target; Anatolii I. Kryvonosov — the creator of highly reliable equipment, as well as Volodymyr O. Uralov — chief designer of the CS of a number of combat missiles, including "Satana", and Borys M. Konorev — the creator of a programming system that had no analogues in the USSR. They were carefully selected and competent specialists; in addition, they also had a desire to work and study. After the integration of the two design bureaus, in fact, the effectiveness of the work of the young team was proved more than once, which subsequently gained confidence in the creation of reliable electrical devices for combat missile control systems.

From the first days of the existence of the new enterprise, SDB-692, a theoretical subdivision began to operate in its structure, which soon grew into an independent and one of the largest subdivisions — the third complex. Specialists to this theoretical department were carefully chosen from young professionals with a penchant for scientific work. The selection took place on an individual basis and, as a rule, even at the stage of the study, in the fifth year or during the graduation project preparation from among the most capable students in the field of mathematics or mechanics. Their diploma projects were carried out at the enterprise, concerned topics related to the enterprise activities and under the guidance of its specialists. The formed third complex had three main directions: ballistics, stabilization, and programming [19, P. 345—351].

In all subsequent works, the leading role in determining the CS shape belonged to the specialists from the third complex. Any discussion of both fundamental and current questions at all levels in and out of the organization did not take place without the participation of the third complex.

The creation of long-range missiles demanded the development of onboard CS based on digital devices and an onboard digital computer. This idea was later implemented in the DB "Elektropriborostroeniya". In the 1970s, first the USSR onboard digital electronic computer was created in the SDB-692. Its

introduction was a revolutionary step in the development of missile and spacecraft control systems. Based on the onboard computer, a test and launch system intended for prelaunch testing of control systems for intercontinental ballistic missiles and launch vehicles was developed in the SDB-692. This system is known as "Electronic launch", and in addition to the missile control system blocks, it included the most powerful computer at that time, BECM-6 (Big Electronic Calculating Machine), which performed 1 million operations per second. Due to this, it made it possible to simulate not only the flight of the rocket but also the reaction of the CS to the influence of various disturbing factors [13].

Under the leadership of Volodymyr H. Serhieiev, control systems were created for four generations of intercontinental ballistic missiles, for three generations of space launch vehicles, and for many types of artificial Earth satellites and spacecrafts.

For fifty years, it has been a leading developer of not only CS but also onboard and ground computing systems, complex electronic equipment for various types of rockets and spacecrafts. Over the years, control systems for intercontinental ballistic missiles have been created, including the world's most powerful combat missile P-36 M2 UTTH (15A18M), which was named in the United States "Satana" (SS-18 "Satan"), "Energiya" and "Cyclone" launch vehicles, "Kvant", "Kvant-2", "Kristall", "Priroda", "Spectrum" orbital modules, and more than 150 satellites of the "Cosmos" series, and other objects [10].

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Received 12.01.2021

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ВНЕСОК ХАРКІВСЬКИХ ПІДПРИЄМСТВ У РОЗВИТОК РАКЕТНО-КОСМІЧНОЇ ГАЛУЗІ

У статті розглядається внесок українських підприємств у розвиток ракетно-космічної галузі. Найважливішою частиною космічної або бойової балістичної ракети є система управління (СУ), від якої залежить успіх її застосування. Харківські підприємства — завод «Комунар» і КБ «Електроприладобудування» (ОКБ-692, нині НВО «Хартрон») були найбільшими виробниками систем управління не лише в Україні, але і у всьому Радянському Союзі. На них не тільки серійно випускалися, але також і розроблялися ці системи. Становлення і розвиток харківських підприємств космічної галузі є найважливішою сторінкою історії розвитку не лише космонавтики, а й науки і техніки в цілому. Незважаючи на велику кількість робіт, присвячених розвитку ракетно-космічної техніки в Україні, історія розробки та виробництва систем управління вивчені недостатньо. Через секретність робіт у галузі ракетно-космічної техніки (РКТ), джерел для дослідження історії її створення вкрай мало. Тому найважливішою частиною роботи стали інтерв'ю з провідними фахівцями ОКБ-692 в галузі систем управління РКТ, а саме з А. М. Калногузом, Ю. А. Кузнєцовим, В. Я. Макаренко, В. Г. Сухоребровим і В. А. Ураловим. На основі цих інтерв'ю був створений спеціальний фонд у Центральному державному науково-технічному архіві України, де можна ознайомитися з цими матеріалами. На рахунку харківських підприємств розробка і серійний випуск систем управління багатьох бойових балістичних ракет, зокрема Р-7, Р-7А, Р-12, Р-16, а також найпотужнішої у світі ракети Р-36М2, що отримала в США назву «Сатана» (SS-18 «Satan»), ракет носіїв «Протон», «Зеніт», «Енергія» і «Циклон», орбітальних модулів «Квант», «Квант-2», «Кристал», «Природа», «Спектр», понад 150 супутників серії «Космос» та ін. об'єктів. У 1970-х роках в ОКБ-692 було створено першу в СРСР бортову цифрову електронно-обчислювальну машину. На її основі був розроблений перевірочно-пусковий комплекс «Електронний пуск», призначений для передстартової перевірки систем керування балістичних ракет і ракет-носіїв.

Ключові слова: космічна галузь, ракета-носій, космічні літальні апарати, бойові балістичні ракети, системи керування, завод «Комунар», КБ «Електроприладобудування», Харківський політехнічний інститут.