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A. A. Baltiyeva [1], A. S. Raskaliyev [2], L. S. Shamganova [1], H. Fan[3], G. B. Abdykarimova[1]

[1]Branch Republican State Enterprise «National center for complex processing of mineral raw materials of the Republic of Kazakhstan» Mining institute after D.A. Kunayev, Almaty, Kazakhstan;
[2]Institute of space technique and technology, Almaty, Kazakhstan;
[3]KTH Royal Institute of Technology, Stockholm, Sweden.
E-mail: a.baltiyeva@gmail.com, raskaliyev@mail.ru, shamls@mail.ru, huaan.fan@abe.kth.se, gylxana@mail.ru

ACCEPTANCE TESTS OF THE SOFTWARE AND TECHNICAL COMPLEX OF THE HIGH-PRECISION SATELLITE POSITIONING SYSTEM IN THE KACHARSKY MINE

Abstract. The world development of science and technology prompts many countries to use their own modern coordinate systems, determined on the basis of satellite measurements. Moreover, the modern system must be characterized by its openness and unity for the entire territory of the country. One of the main problems arising during the creation and operation of our own high-precision positioning satellite systems in the Republic of Kazakhstan are: the lack of domestic satellite equipment, specialized software and test methods for the software and hardware complex.

A unique opportunity appeared in the development and testing of the software and hardware complex of the high-precision satellite positioning system at the Kacharsky open pit thanks to the funding of the Science Committee of the Ministry of Education and Science of the Republic of Kazakhstan through grants for scientific and technical projects for 2018–2020 (grant No. AP05136083) and co-financing of the private partner JSC «SSGPO».

The article presents the results of technical solutions for the implementation of a high-precision satellite positioning system, in particular, the creation of a permanent base station (BS) of global navigation satellite systems (GNSS) at operating open pit. The primary purpose of the work is to provide high-precision positioning of an open field in order to determine geodetic coordinates using modern satellite navigation technologies in real-time and post-processing. This development continues the path of introducing the elements of Industry 4.0, which is currently being carried out at the Kacharsky open pit.

Key words: GNSS, satellite high-precision positioning system, mine, base station of differential correction (BSDC), acceptance tests, center of differential correction (DCC).

Introduction. This article presents the results executed during acceptance tests for the introduction of a high-precision satellite positioning system into commercial operation at the Kacharsky open pit. The tests were carried out in joint cooperation with the project co-executor (Institute of space technique and technology) and a private partner (JSC «SSGPO»).

In particular, the following works were implemented in the tasks of solving the problems of commissioning:

- installation and adjustment works of the base station of differential correction (BSDC);
- preliminary tests of differential correction center (DCC);
- preliminary tests of the high-precision satellite positioning system;
- trial operation of a high-precision satellite positioning system;
- acceptance tests of a high-precision satellite positioning system for commercial operation.

Installation and adjustment works of the base station of differential correction. A permanent geodetic point with the name "Base" was installed on the roof of the administrative building (AB) during the installation process. At this geodetic point, a GNSS antenna was mounted along with the corresponding cables, which is part of the BSDC.

The following locations were checked in the process of testing: a geodetic point on the parapet of the AB; navigation and transmitting complexes of BSDK on the buildings of the AB, the Control room, as well as on the antenna mast near the Control room (see figure 1). The compliance of the location of the geodetic point and the complexes of the BSDC were checked in accordance with the requirements of technical, industrial safety and working-design documentation of the SVSN (high-precision satellite navigation system) [1,2].

The possibilities of functioning, operability, and technical characteristics of the three complexes of the BSDC were tested separately and in general when the BSDC was operating as one system. The tests were accomplished on the BSDC complexes, which are considered to have passed the tests: after turning on the equipment as part of the BSDC, they operate in a normal mode and do not give false information in any operating modes. The parameters correspond to the established operating modes of the equipment as part of the BSDC, the characteristics correspond to the data specified in the operational documentation for these products.

Based on the results of checking the functional purpose of the BSDC and checking the operability and technical characteristics of the BSDC, the following was revealed:

– the obtained technical characteristics of the tested complexes of the BSDC correspond (do not exceed) the declared by BSDC developer;

– operability and compliance with the specified technical characteristics of the BSDC are confirmed by the Protocol of installation and adjustment works;

– fabrication and installation of a geodetic point in accordance with the requirements of SSGPO is confirmed by the Protocol of installation and adjustment works.

Installation and adjustment works of this stage were successfully carried out in the fall of 2019.

Pilot and industrial tests of the system were performed in August 2020 and are presented below.

Figure 1 – VHF antennas of the BSDC transmitting complex on the Control's room antenna mast

Preliminary tests of the center for differential correction. The Center for Differential Correction (DCC) is a software and hardware complex for controlling and monitoring the state of the base station of differential correction (BSDC), which in turn refers to systems for receiving and processing navigation signals, as well as issuing correcting satellite navigation information. The DCC is also used to receive, process, and transmit satellite navigation parameters via the Internet.

Preliminary tests of the DCC were carried out in connection with the completion of work on the creation of a differential correction center (DCC) for the base station of differential correction (BSDC).

The purpose of the tests was a comprehensive check of the operability of the hardware and software of the DCC, as well as checking the functionality during its interaction and joint performance of tasks with the BSDC.

Preliminary tests were performed according to the following list of testing the functions of the DCC, presented in figure 2.

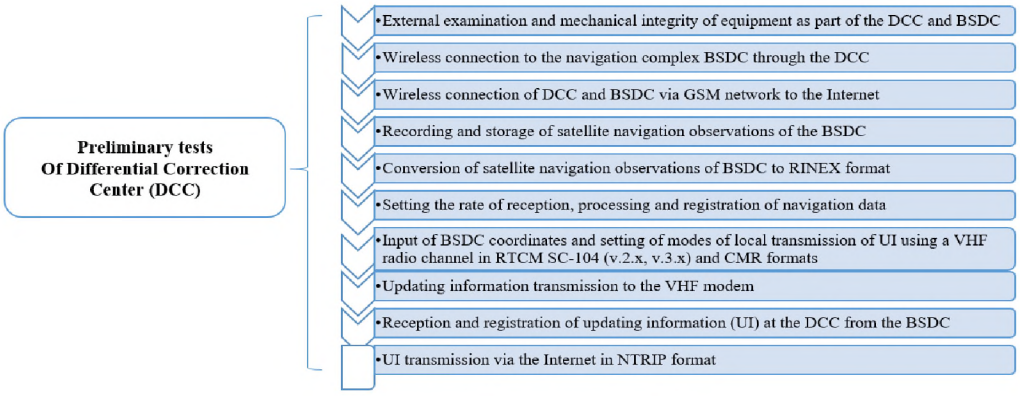

Figure 2 – List of testing the functions of the DCC

Failures, failures and emergencies in the work of the DCC were not revealed during the tests.

Results and conclusions on preliminary tests of the DCC:

– hardware and software of the DCC effectively interact with the BSDC and allow the BSDC to perform the functions assigned to it;

– the functionality of the DCC fully covers the functionality of the software (S) described in the project documentation "Specification of the BSDC", "Manual for the operation of the BSDC" and "Operator's manual for the processing of satellite measurement data".

Preliminary tests of the high-precision satellite positioning system. The purpose of the preliminary tests was a comprehensive check of the operability of the hardware and software of the high-precision positioning system (HPPS), which consists of three parts, namely the base station of differential correction (BSDC), the center of differential correction (DCC) and the geodetic point "Base" on the roof of the Mine Administration.

During the preliminary tests, systematic discrepancies in the measurements of the GNSS rover were revealed when using corrections from the BSDC and the “basa kachar” base station, previously installed at the Kacharsky mining complex. The reason for the discrepancy was the binding of the “basa kachar” base station to the local coordinate system (LCS) of the Kacharsky mine, while the installed BSDC was linked to the international coordinate system ITRF-2014. On the recommendation of the representatives of JSC «SSGPO», the coordinate values entered in the BSDC were changed by binding to the local frame of reference of the Kacharsky open pit in order to eliminate the discrepancies.

Arbitrary points have been measured by a rover in the study area to compare coordinates and elevations in the LCS when receiving corrections through VHF channels from the “basa kachar” and BSDC base. The results of calculating the discrepancies in the measurement values at 12 randomly selected points and the analysis of these discrepancies are presented in table 1.

As can be seen from Table 1, the discrepancies were systematic. On average, the differences were 1.996 meters north, 2.281 meters east and 1.293 meters in height, with a variation coefficient of 0.85% north, 1% east, and 7% in height. Therefore, it was assumed that the reason for the discrepancies was the displacement of the centers of the coordinate systems relative to which the rover coordinates were measured using corrections from two different base stations. The reason for the discrepancy was the definition and assignment of coordinates of the base "basa kachar" and BSDC in different coordinate systems. The coordinates "basa kachar" were determined in the LCS of the Kacharsky open-pit mine, while the coordinates of the BSDC, according to the previously made draft and technical design, were determined in the international coordinate system ITRF-2014 [3,4].

The coordinates of the BSDC were redefined and set this time in the LCS of the Kacharsky open pit to eliminate the discrepancy. Particularly, it was decided to determine and set the coordinates of the phase center of the GNSS antenna of the BSDC using the differential correction operation relative to the base station "basa kachar". This operation included joint processing of satellite navigation measurements in the RINEX format, made simultaneously for 6 hours on the basis of "basa kachar" and BSDC. New coordinates for the BSDC were determined and set as a result of the operation.

Table 1 – Analysis of discrepancies between measurements at corresponding points

Measurement name	North (X, meters)	East (Y, meters)	Height (meters)
1	1,974	-2,319	1,008
2	2,003	-2,279	1,317
3	1,997	-2,287	1,341
4	1,993	-2,288	1,326
5	1,987	-2,304	1,333
6	1,975	-2,297	1,331
7	1,984	-2,297	1,320
8	2,000	-2,255	1,312
9	1,991	-2,288	1,311
10	2,037	-2,244	1,302
11	2,010	-2,270	1,304
12	2,002	-2,248	1,313
Expected value	1,9960833	-2,28133	1,293167
Dispersion	0,0002875	0,000534	0,008205
Standard deviation	0,0169569	0,023114	0,090581
The coefficient of variation	0,0085	-0,01013	0,070046

The discrepancies in the measurements of the GNSS rover when using corrections from the BSDC and the base station "basa kachar" were minimized and constitute an acceptable error within the normal range after setting the new coordinates.

Trial operation of a high-precision satellite positioning system. The purpose of the trial operation was to determine the actual values of the quantitative and qualitative characteristics of the high-precision positioning system and the readiness of the mine surveyor service to work in the conditions of its functioning, to determine the actual efficiency of the hovercraft, as well as to correct the corresponding working design documentation.

During the trial operation the following components were checked: technical; software and information support for HPPS; according to the lists presented in figure 3.

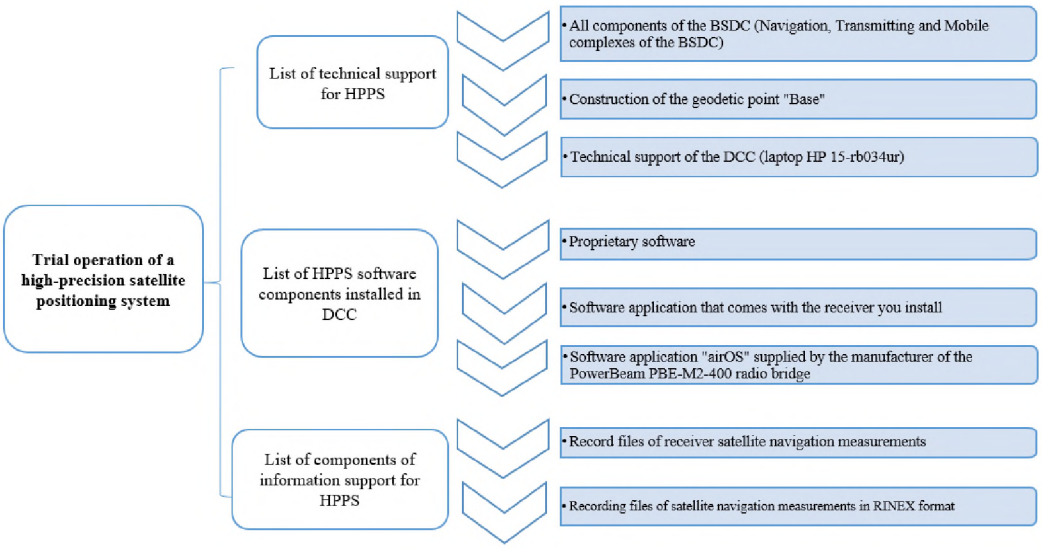

Figure 3 – List of tests during trial operation

The following verification results were obtained: the trial operation program was completed in full; the mine surveying service of the Kacharsky mining complex has high competence when performing work using the functionality of the HPPS; HPPS and its technical documentation are ready for commissioning.

Acceptance tests of the high-precision satellite positioning system into commercial operation. BSDC and DCC were developed as a result of the creation of a high-precision satellite positioning system (see figure 4). BSDC is a ground-based fixed station for receiving and processing GLONASS/GPS/BeiDou signals. The base station of differential correction is intended for the automated reception of navigation signals, processing, storage, and provision of navigation data to consumers in the served area, as well as for transmission of navigation data and service information to the DCC. The satellite navigation antenna of the BSDC was fixed in the geodetic point "Base" on the roof of the mine administration. The "Base" point is included in the geodetic reference network of the Kacharsky field of JSC SSGPO, the coordinates of which were in SC WGS-84 and consequently recalculated in SC ITRF-2014 in order to link to the international geodetic network IGS and to the local coordinate system.

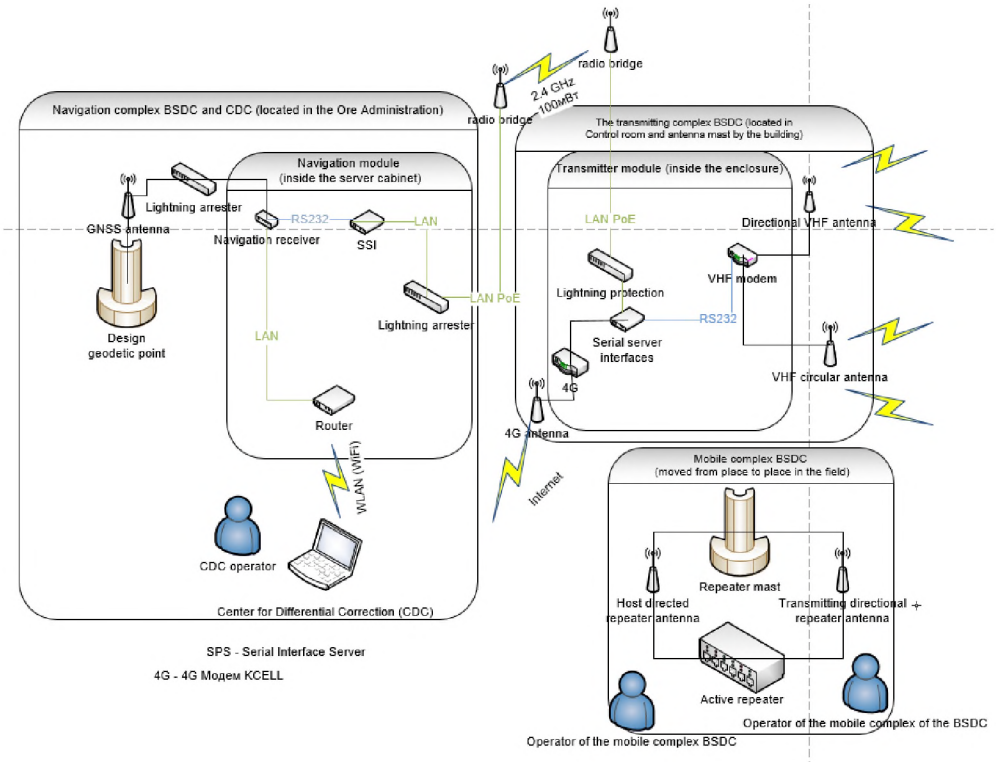

Figure 4 – Location of the BSDC complexes

The scientific and technical level of the development of this system corresponds to the world level of development of permanent GNSS base stations. The developed system and its technical documentation were taken into commercial operation.

Conclusion. The significance of this project is to ensure high-precision positioning of mining allotments and will allow solving two main problems of open-pit mining in the near future: increasing labor productivity through the introduction of digital technologies and significantly increasing the industrial and environmental safety of mining operations [5]. The experience of implementing a high-precision positioning system at the Kacharsky field makes it possible to use it at other mining enterprises in Kazakhstan.

It should be noted that there is an increased interest abroad in solving engineering-geodetic and cadastral problems based on the technology of Continuously Operating Reference Station (CORS). CORS was implemented in the United States by the National Geodetic Service (NGS) in 1995. In 2008, CORS united more than 1500 stations of various organizations throughout the country and continues to expand rapidly [6,7]. These stations are independently operated. Each owner provides his data to the NGS service,

which analyzes, processes, and distributes them free of charge for post-processing [8,9]. The authors see the same development prospects when creating a unified coordinate, time, and navigation support system for our country. Considering the scale of the use of satellite technologies when performing engineering-geodetic and cadastral works, equalizing the coordinates of single base stations and creating permanent reference networks in the territory of the Republic of Kazakhstan is an urgent task [1].

А. А. Балтиева[1], А. С. Раскалиев[2], Л. С. Шамганова[1], Х. Фан[3], Г. Б. Әбдікәрімова[1]

[1]«Д. А. Қонаев атындағы Тау-кен институты» «ҚР МШКҚӨ ҰО» РМК, Алматы, Қазақстан;
[2]Ғарыштық техника және технологиялар институты, Алматы, Қазақстан;
[3]Корольдік технологиялық институт, Стокгольм, Швеция

ҚАШАР КАРЬЕРІНДЕ ДӘЛДІГІ ЖОҒАРЫ СПУТНИКТІК ЖАЙҒАСТЫРУ ЖҮЙЕСІНІҢ БАҒДАРЛАМАЛЫҚ-ТЕХНИКАЛЫҚ КЕШЕНІН ҚАБЫЛДАУ СЫНАҚТАРЫ

Аннотация. Ғылым мен техниканың әлемдік даму жағдайы көптеген елді жерсеріктік өлшеулер негізінде анықталған өздерінің заманауи координаттар жүйесін қолдануға итермелейді. Сонымен қатар, қазіргі заманғы жүйе бүкіл ел үшін өзінің ашықтығы мен бірлігі арқылы сипатталуы керек. Қазақстан Республикасында тиесілі жоғары дәлдікті жерсеріктік жайғастыру жүйелерін құру және пайдалану кезінде туындайтын негізгі мәселенің бірі – отандық жерсеріктік аппаратураның, мамандандырылған бағдарламалық қамтылым мен бағдарламалық-техникалық кешенді сынау әдістемесінің болмауы.

ҚР БҒМ Ғылым комитетінің 2018-2020 жылдарға арналған ғылыми-техникалық жобаларға гранттар (№AP05136083 грант) желісі бойынша қаржыландыру және «ССКӨБ» АҚ жеке әріптесін қоса қаржыландыруының арқасында Қашар карьерінде дәлдігі жоғары жерсеріктік жайғастыру жүйесінің бағдарламалық-техникалық кешенін әзірлеу мен апробациялауда бірегей мүмкіндік пайда болды.

Әзірленген дифференциалды түзетудің базалық станциясы навигациялық сигналдарды автоматты қабылдауға, қызмет көрсетілетін аумақтағы навигациялық деректерді өңдеуге, сақтауға және тұтынушыларға ұсынуға, сондай-ақ навигациялық деректер мен қызметтік ақпаратты сараланған түзету орталығына беруге арналған. Дифференциалды түзетудің базалық станциясының (ДТБС) спутниктік навигациялық антеннасы кен басқармасының төбесіндегі «База» геодезиялық пунктіне бекітілді. «База» пункті «ССК-84 координаттары IGS халықаралық геодезиялық желісіне және жергілікті координаттар жүйесіне байланыстыру мақсатында ITRF-2014 СК қайта есептелген «ССКӨБ» АҚ Қашар кен орнының тірек геодезиялық желісіне кіреді.

Мақалада Қашар карьерінде өнеркәсіптік пайдалануға жоғары дәлдікті жерсеріктік жайғастыру жүйесін енгізу үшін қабылдау сынақтарын жүргізуде орындалған нәтижелер ұсынылған. Сынақтар жобаның бірлескен орындаушысымен (Ғарыштық техника және технологиялар институты) және жеке серіктеспен («ССКӨБ» АҚ) бірлесіп жүргізілді. Атап айтқанда, дифференциалды түзету базалық станциясының монтаждау және іске қосу-жөндеу жұмыстары; дифференциалды түзету орталығының алдын ала сынақтары; жүйенің алдын ала және тәжірибелік сынақтары жүргізілді.

Дифференциалды түзету орталығының (ДТО) функцияларын тестілеу және тәжірибелік пайдалану кезінде тексеру жүргізілген тізбелер келтірілген. Жүргізілген сынақтардың негізгі міндеттері мынадай: ДТО-ның техникалық және бағдарламалық қамтамасыз етуінің жұмысқа қабілеттілігін кешенді тексеру, сондай-ақ ДТО-ның өзара екіжақты қатынасы мен міндеттерін ДТБС-мен бірлесіп орындау кезінде оның функционалдығын тексеру; жоғары дәлдікті позициялау жүйесінің (ЖПЖ) техникалық және бағдарламалық қамтамасыз етулерінің жұмысқа қабілеттілігін кешенді тексеру; жоғары дәлдікті позициялау жүйесінің сандық және сапалық сипаттамаларының нақты мәнін және маркшейдерлік қызметтің жұмыс істеу жағдайындағы жұмысқа дайындығын айқындау, ЖПЖ нақты тиімділігін анықтау, сондай-ақ тиісті жұмыс конструкторлық құжаттамасын түзету.

Осы жүйені әзірлеудің ғылыми-техникалық деңгейі ҒНСЖ тұрақты жұмыс істейтін базалық станцияларын әзірлеудің әлемдік деңгейіне сәйкес келеді. Әзірленген жүйе және оның техникалық құжаттамасы өнеркәсіптік пайдалануға қабылданды.

Жалпы жұмыстың негізгі мақсаты – нақты уақыт және өңдеуден кейінгі режимде заманауи серіктік навигациялық технологиялар арқылы геодезиялық координаталарды анықтау үшін ашық кен орнын жоғары дәлдікті жайғастырумен қамтамасыз ету. Қазіргі уақытта Қашар карьерінде жүзеге асырылып жатқан әзірленген жүйе (ЖПЖ) Индустрия 4.0 элементтерін енгізу жолын жалғастыруда.

Түйін сөздер: ҒНСЖ, жоғары дәлдікті позициялаудың спутниктік жүйесі, карьер, дифференциалды түзетудің базалық станциясы (ДТБС), қабылдау сынақтары, дифференциалды түзету орталығы (ДТО).

А. А. Балтиева[1], А. С. Раскалиев[2], Л. С. Шамганова[1], Х. Фан[3], Г. Б. Әбдікәрімова[1]

[1]РГП «НЦ КПМС МИР РК» Институт горного дела им. Д. А. Кунаева, Алматы, Казахстан;
[2]Институт космической техники и технологий, Алматы, Казахстан;
[3]Королевский технологический Институт, Стокгольм, Швеция

ПРИЕМОЧНЫЕ ИСПЫТАНИЯ ПРОГРАММНО-ТЕХНИЧЕСКОГО КОМПЛЕКСА СИСТЕМЫ ВЫСОКОТОЧНОГО СПУТНИКОВОГО ПОЗИЦИОНИРОВАНИЯ НА КАЧАРСКОМ КАРЬЕРЕ

Аннотация. Мировое развитие науки и техники побуждает многие страны применять собственные современные системы координат, определенные на основе спутниковых измерений. При этом современная система должна характеризоваться своей открытостью и единством для всей территории страны. Одними из основных проблем, возникающих при создании и эксплуатации собственных спутниковых систем высокоточного позиционирования в Республике Казахстан, являются: отсутствие отечественной спутниковой аппаратуры, специализированного программного обеспечения и методики испытаний программно-технического комплекса.

Благодаря финансированию Комитета науки МОН РК по линии грантов на научно-технические проекты (грант № AP05136083) на 2018–2020 гг. и софинансированию частного партнера АО «ССГПО», появилась уникальная возможность в разработке и апробировании программно-технического комплекса системы высокоточного спутникового позиционирования на Качарском карьере.

Разработанная базовая станция дифференциальной коррекции предназначена для автоматизированного приёма навигационных сигналов, обработки, хранения и предоставления потребителям навигационных данных на обслуживаемой территории, а также для передачи навигационных данных и служебной информации в центр дифференциальной коррекции. Спутниковая навигационная антенна базовой станции дифференциальной коррекции (БСДК) была закреплена на геодезическом пункте «База» на крыше рудоуправления. Пункт «База» входит в опорную геодезическую сеть Качарского месторождения АО «ССГПО», координаты которой в СК WGS-84 были пересчитаны в СК ITRF-2014 с целью привязки к международной геодезической сети IGS и в местную систему координат.

В статье представлены результаты, выполненные при проведении приёмочных испытаний для введения системы высокоточного спутникового позиционирования в промышленную эксплуатацию на Качарском карьере. Испытания проводились совместно с соисполнителем проекта (Институт космической техники и технологий) и частным партнером (АО «ССГПО»). В частности, были проведены: монтажные и пусконаладочные работы базовой станции дифференциальной коррекции; предварительные испытания центра дифференциальной коррекции; предварительные и опытные испытания системы.

Приведены перечни, по которым проводилось тестирование функций центра дифференциальной коррекции (ЦДК) и проверки при опытной эксплуатации. Основные задачи проведенных испытаний заключаются в следующем: комплексная проверка работоспособности технического и программного обеспечений ЦДК, а также проверка функциональности ЦДК при его взаимодействии и совместном выполнении задач с БСДК; комплексная проверка работоспособности технического и программного обеспечений системы высокоточного позиционирования (СВП); определение фактических значений количественных и качественных характеристик системы высокоточного позиционирования и готовности маркшейдерской службы к работе в условиях его функционирования, определение фактической эффективности СВП, а также корректировка соответствующей рабочей конструкторской документации.

Научно-технический уровень разработки данной системы соответствует мировому уровню разработок постоянно действующих базовых станций ГНСС. Разработанная система и ее техническая документация приняты в промышленную эксплуатацию.

Основной целью всей работы является обеспечение высокоточным позиционированием открытого месторождения, для определения геодезических координат с помощью современных спутниковых навигационных технологий в режимах реального времени и постобработки. Данная разработка продолжает путь внедрения элементов Индустрии 4.0, который в настоящее время осуществляется на Качарском карьере.

Ключевые слова: ГНСС, спутниковая система высокоточного позиционирования, карьер, базовая станция дифференциальной коррекции (БСДК), приемочные испытания, центр дифференциальной коррекции (ЦДК).

Information about authors:

Baltiyeva A.A., Head of laboratory, Branch Republican State Enterprise «National center for complex processing of mineral raw materials of the Republic of Kazakhstan» Mining Institute named after D. A. Kunayev, Almaty, Kazakhstan; a.baltiyeva@gmail.com; https://orcid.org/0000-0003-1089-3351

Raskaliyev A.S., PhD, Institute of space technique and technology, Almaty, Kazakhstan; raskaliyev@mail.ru; https://orcid.org/0000-0003-4287-4286

Shamganova L.S, professor of Mining, doctor of technical sciences, corresponding member of the National Academy of Sciences of the Kazakhstan Republic, Deputy Director for Research, Branch Republican State Enterprise «National center for complex processing of mineral raw materials of the Republic of Kazakhstan» Mining Institute named after D. A. Kunayev, Almaty, Kazakhstan; shamls@mail.ru; https://orcid.org/0000-0001-5903-5118

Huaan Fan, Associate professor, Royal Institute of Technology (KTH), Stockholm, Sweden; huaan.fan@abe.kth.se; https://orcid.org/0000-0001-9689-1597

Abdykarimova G.B., PhD student, Branch Republican State Enterprise «National center for complex processing of mineral raw materials of the Republic of Kazakhstan» Mining Institute named after D. A. Kunayev, Almaty, Kazakhstan; gylxana@mail.ru; https://orcid.org/0000-0002-0767-7538

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