ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)

ҚАЗАҚСТАН РЕСПУБЛИКАСЫ
ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫ
Satbayev University

Х А Б А Р Л А Р Ы

ИЗВЕСТИЯ

НАЦИОНАЛЬНОЙ АКАДЕМИИ НАУК
РЕСПУБЛИКИ КАЗАХСТАН
Satbayev University

N E W S

OF THE ACADEMY OF SCIENCES
OF THE REPUBLIC OF KAZAKHSTAN
Satbayev University

SERIES
OF GEOLOGY AND TECHNICAL SCIENCES

5 (449)

SEPTEMBER – OCTOBER 2021

THE JOURNAL WAS FOUNDED IN 1940

PUBLISHED 6 TIMES A YEAR

ALMATY, NAS RK

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«ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы».
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)

Меншіктеуші: «Қазақстан Республикасының Ұлттық ғылым академиясы» РҚБ (Алматы қ.).

Қазақстан Республикасының Ақпарат және қоғамдық даму министрлігінің Ақпарат комитетінде 29.07.2020 ж. берілген **№ KZ39VPY00025420** мерзімдік басылым тіркеуіне қойылу туралы куәлік.

Тақырыптық бағыты: *геология, мұнай және газды өңдеудің химиялық технологиялары, мұнай химиясы, металдарды алу және олардың қосындыларының технологиясы.*

Мерзімділігі: жылына 6 рет.

Тиражы: 300 дана.

Редакцияның мекен-жайы: 050010, Алматы қ., Шевченко көш., 28, 219 бөл., тел.: 272-13-19

http://www.geolog-technical.kz/index.php/en/

Типографияның мекен-жайы: «Аруна» ЖК, Алматы қ., Мұратбаев көш., 75.

«Известия НАН РК. Серия геологии и технических наук».
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)

Собственник: Республиканское общественное объединение «Национальная академия наук Республики Казахстан» (г. Алматы).

Свидетельство о постановке на учет периодического печатного издания в Комитете информации Министерства информации и общественного развития Республики Казахстан **№ KZ39VPY00025420,** выданное 29.07.2020 г.

Тематическая направленность: *геология, химические технологии переработки нефти и газа, нефтехимия, технологии извлечения металлов и их соеденений.*

Периодичность: 6 раз в год.

Тираж: 300 экземпляров.

Адрес редакции: 050010, г. Алматы, ул. Шевченко, 28, оф. 219, тел.: 272-13-19

http://www.geolog-technical.kz/index.php/en/

Адрес типографии: ИП «Аруна», г. Алматы, ул. Муратбаева, 75.

News of the National Academy of Sciences of the Republic of Kazakhstan. Series of geology and technology sciences.

ISSN 2518-170X (Online),

ISSN 2224-5278 (Print)

Owner: RPA «National Academy of Sciences of the Republic of Kazakhstan» (Almaty).

The certificate of registration of a periodical printed publication in the Committee of information of the Ministry of Information and Social Development of the Republic of Kazakhstan **No. KZ39VPY00025420,** issued 29.07.2020.

Thematic scope: *geology, chemical technologies for oil and gas processing, petrochemistry, technologies for extracting metals and their connections.*

Periodicity: 6 times a year.

Circulation: 300 copies.

Editorial address: 28, Shevchenko str., of. 219, Almaty, 050010, tel. 272-13-19

http://www.geolog-technical.kz/index.php/en/

Address of printing house: ST «Aruna», 75, Muratbayev str, Almaty.

NEWS
OF THE NATIONAL ACADEMY OF SCIENCES OF THE REPUBLIC OF KAZAKHSTAN **SERIES OF GEOLOGY AND TECHNICAL SCIENCES**
ISSN 2224-5278
Volume 5, Number 449 (2021), 94-102 ***https://doi.org/10.32014/2021.2518-170X.103***

UDC 550.377
IRSTI37.15.29;37.15.23;37.15.21

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HARDWARE-SOFTWARE COMPLEX FOR THE TELLURIC CURRENT INVESTIGATION IN A SEISMICALLY HAZARDOUS REGION OF ZAILIYSKY ALATAU

Abstract. To solve the current issues of detecting seismoelectric signals at preparing earthquakes, a hardware-software complex was created, designed to study the telluric current variation in the ultra-low frequency range (0-20 Hz), which is installed in the seismically active region of the Zailiysky Alatau (Northern Tien Shan) near the foci of the Vernensky M7.3 and Keminsky M8.2 catastrophic earthquakes. Special mathematical algorithms and program tools were designed for continuous registration, real-time data analysis, and visualization of the information on telluric current. It was proposed an effective system for reducing the influence of stray currents on the measuring equipment, an optimal lightning protection scheme, and a grounding system for the power supply devices, which allow uninterrupted measurements in mountain conditions even in time of close intensive thunderstorm. The capabilities of the hardware-software complex make it possible to detect both the weak electric signals with an amplitude of several tens–hundred of microvolts only, and intensive electromagnetic pulses from close lightnings without the damage of registering apparatus. In the records of telluric current the wave oscillations were detected which belong to the frequency range of the Pc2–Pc4 class micropulsations of the geomagnetic field. Perspectives of the detection of seismogenic electrical signals in variations of telluric current on the eve and during earthquakes are connected with data obtained during the earthquake of magnitude MPV 4.5, which occurred on July 1, 2021 at 60.4 km from the measuring point. At the time of the earthquake, immediately after the main shock, in conditions of «good weather» and low industrial noise, using the calculation of the dynamic power spectrum of the telluric current in the frequency range 0.2 Hz - 0.0282 Hz, electrical signals were detected, presumably of seismogenic origin.

Key words: hardware-software complex, telluric current, seismogenic electrical signal.

Introduction. Presently, monitoring of the telluric current variation is actively used for investigation of the processes which take place in the lithosphere in their interconnection with various geophysical phenomena [1,2,3,4]. The appearance in low-frequency electrical pulses of the ULF/ELF range before earthquakes is considered as a signal, presumably associated with the processes of electrification of rocks during the activation of deformation processes in the area of earthquake preparing, which gives hope for the detection of short-term precursors of earthquakes [5,6,7].Identification of the electrical pulses of seismic origin against an intensive background of industrial noises, magnetospheric and lightning interference is a rather complicated task. In the countries with developed industry much attention by investigation of the telluric current in seismically hazardous zones is paid to the noise induced by stray currents which mask the useful signal [3]. The possibility of detecting the seismoelectric signals in telluric currentvariation, in the absence of magnetospheric and thunderstorm interference [3,8,9], is used to study connection electric signals with processes of earthquake preparation. The most earthquake-prone areas in Kazakhstan is the Northern Tien Shan region, which covers the Zailiyskiy and Kungey Alatau ridges.In this highly seismic region, near the epicenters of the Vernensky M7.3 (1887) and Keminsky M8.2 (1911) catastrophic earthquakes, there is the largest metropolis of Kazakhstan Almaty city. In a mountain area, 32 km from the city at an altitude of 3340 m far from industrial interferenceis located the scientific station «Kosmostantsiya» [N 43.0435^o E 76.9414^o].

On the territory «Kosmostantsiya»is being carried out monitoring the parameters of geophysical fields from the lithosphere (borehole observations), the surface atmosphere to the heights of the ionosphere. Gamma, neutron, temperature and acoustic detectors are used for monitoring [10, 11, 12]. It should be especially noted an uniqueness of such close disposition of the geophysical measurement site to the Vernensky and Keminsky catastrophic earthquakes (see Fig.1).

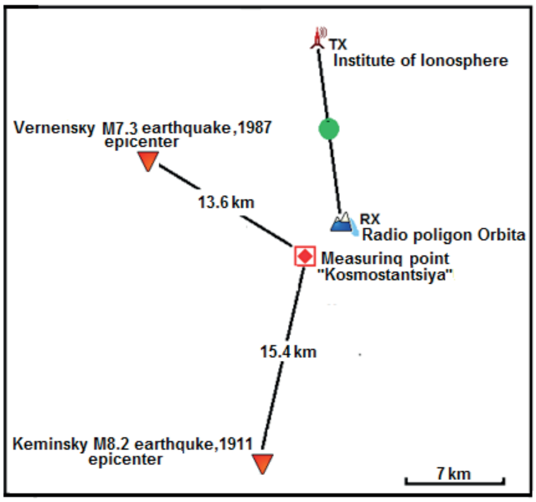
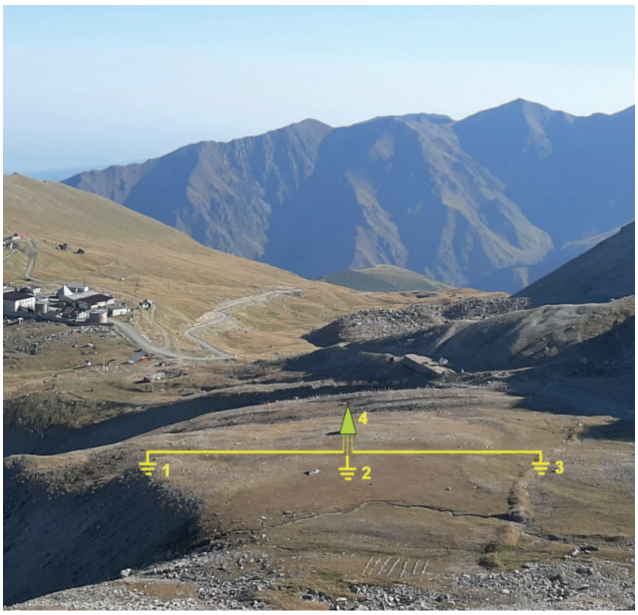


Figure 1 –Scheme of disposition of scientific stations «Kosmostantsiya» and «RadiopoligonOrbita» relatively to the epicenters of catastrophic earthquakes

At present a hardware-software complex has been created, which is aimed to study the telluric current variation and is included in the complex of geophysical observations. The subject of the present paper is the description of the hardware and program means designed for the purpose, and presentation of the first monitoring results of the telluric current behavior in the seismically active region around the Almaty city.

Methodology and hardware-software equipment. Hardware-software complex for continuous monitoring of telluric current variation far from industrial interference and an algorithm of abnormal signals detection of seismogenic origin in the range of 0-20 Hz have been developed. As shown in Fig. 2, the telluric current registration point is locatedin the glacial circusat an altitude of 3460 m approximately 0.7 kmfrom «Kosmostantsiya» and 32 km from Almaty city, that is far away from industrial interference, where road communicationis provided only by road transport.



1 and 3 –ground electrodes used to measure telluric current variation, spaced 120 m from each other; 2 –ground electrode; 4 –measuring equipment point [43,03692°N76,94230° E]

Figure 2 – Location of point for telluric current measuring at scientific station «Kosmostantsiya»at 3460 m

The symmetric input signal is taken from the two electrodes 1 and 3 relative to the middle point electrode 2. The functional scheme of the electronics used for the measurement of telluric current is shown in Fig.3.

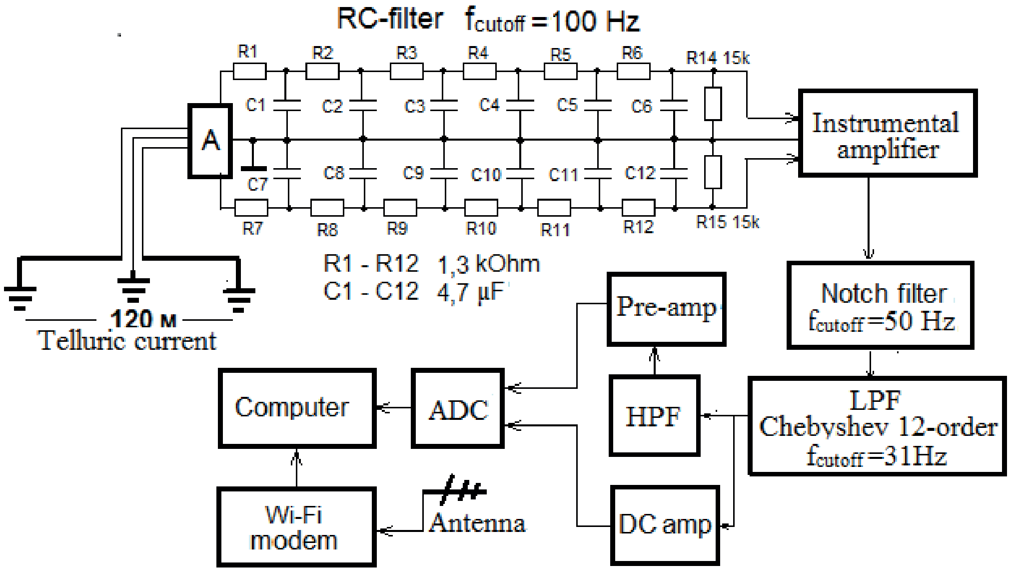


Figure 3 – Functional scheme of the electronic equipment for investigation of the telluric current variation

The telluric current is measured between two lead electrodes which are vertically buried in the ground and located at a distance of 120 m from each other. The signal from the electrodes passes sequentially through the discharge system (A) and is fed to a six-link symmetric RC-filter (low-pass filter). The RC-filter makes it possible to weaken the signals of the radio stations which generate interference at the input of the measuring amplifier. Balanced signal is then amplified by an «Instrumental Amplifier» which uses Texas Instruments' OPA-27GP of low-noise precision operational amplifiers.These precision microcircuits have a high sensitivity of 3.8 nV / √Hz at a frequency of 10 Hz and a temperature stability of 0.27 µV /^{0}C. The amplified signal is fed to the «Notch filter» with a cutoff frequency fcutoff=50 Hz, where the 50 Hz frequency of industrial network is suppressed by about 40 dB. The final filtering of the signal takes place in a low-pass filter «12-order Chebyshev LPF» with a cutoff frequency fcutoff= 32 Hz, which also uses precision operational amplifiers OPA-27GP.The suppression of signals by the low-pass filter above the filter cutoff frequency is at least 80 dB.

Then the filtered signal is simultaneously fed to a DC amplifier, and to a high-pass filter with the lower cutoff at 0.08 Hz, where the DC component is eliminated completely. Further, the filtered signal is simultaneously fed to the DC amplifier (DC amp) and the high-pass filter (HPF) with a cutoff frequency fcutoff=0.08 Hz, where the constant component is cut off and then the signal is amplified by amplifier Pre-amp.Such division of the signal is necessary to increase the dynamic range of recorder, separate digitization of signals of telluric current slow variation and its high-frequency component.The total amplification coefficient of the input signal in the channel with DC component is 54 dB, and in the high frequency channel it equals to 75 dB. The analogue signals at the output of both amplifiers are continuously digitized with periodicity of 25 Hz by a 12-bit «ADC» of the L-card E-154 firm, and the monitoring records obtained are kept in a textual file at the disk of a control computer.The interconnection with the ADC card and real-time control for the measurement process are supported by a specially designed program. The outer graphic interface of this program during the measurements looks like a picture in Fig. 4. Any transmission of resulting measurement data from the detector point into the common database of the «Kosmostantsiya» center, and remote control of the registration program are realized via a Wi-Fi modem connected to the computer network of the center. The local time of the registration computer is synchronized automatically through the same network using NTP (Network Time Protocol) time servers in the Internet.

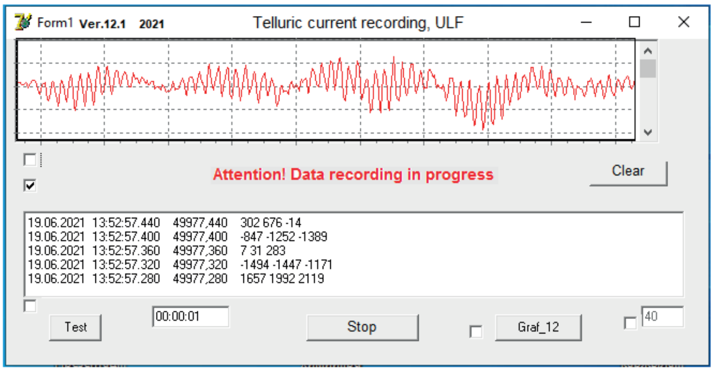


Figure 4 – The graphic interface of the control program for recording the telluric current variation

Telluric current is monitored in mountain area, where during the spring-summer period there is very high thunderstorm activity.Initially, attempts to register the TC signals during thunderstorm led to the failure of the input amplifier microcircuits of the receiving device at the very first lightning flash. Therefore, special attention was paid to the protection of electronic equipment against close lightning discharges and the development of special lightning protection schemes.

In the functional scheme of Fig. 3 the system of lightning protection is designated as block A. In Fig. 5 the internal arrangement of block Ais shown in more details.

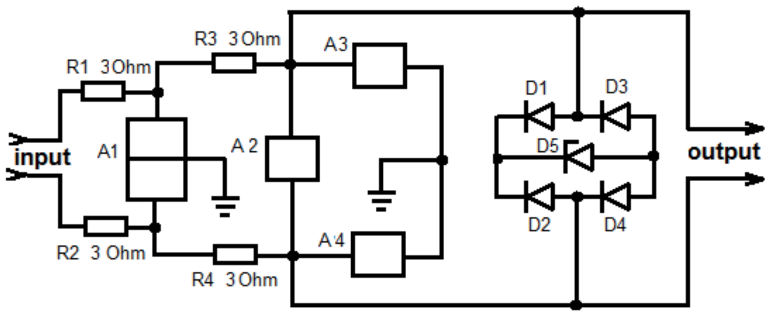


Figure 5 – The lightning protection scheme of input circuitry of the telluric current detector (block A)

As shown in Fig. 5, the protection blockAuses a three-stage schematic which realizes a step-by-step reduction of the overvoltage pulses induced by lightning discharges. The first stage of protection is composed by gas discharger A1 of the P-64 type (Russian production) which has a dynamic breakdown threshold 3 kV and sustains the pulse discharge current up to 1 kA. The symmetric input signal from the grounding electrodes 1and 3 (see Fig. 2) is connected to this discharger through the resistors R1 and R2. Further on, via resistors R3 and R4, the signal fed to the second protection stage consisting of discharger A2 which connects two wires of the symmetric line, and dischargers A3 and A4 which close both lines into the ground. In the second protection stage the dischargers of P-73 type (Russian production) are used which have the voltage of static breakdown at 90V. The third protection stage is composed by a semiconductor diode bridge D1–D4 and Zener diode D5 which limits lightning impulses to safe a limit of 6V. Such three-stage protection scheme provided reliable round-the-clock operability of the telluric current recording equipment during the period of thunderstorm activity and lightning discharges. It should be stressed that effective lightning protection can be achieved only under condition of appropriately realized grounding.

Besides lightning, essential interference by the measurement of telluric current arises because of stray currents induced in the ground by using it as a conducting medium. In our case, the power supply of measuring point is carried out via a cable about 400 m long from the 220V power grid.Industrial noises can propagate over this cable and cause induction of stray currents in the vicinity of the measurement point.

The electrical cable is also a good «antenna» under thunderstorms. At time of lightning flashes, significant voltages and currents are induced in the electric cable that can damage the recording equipment. Therefore, a special work was carried out to divide and spatiality separate the TC recorder grounding systems from the circuits of the grounding system of power supply devices (Fig. 6).

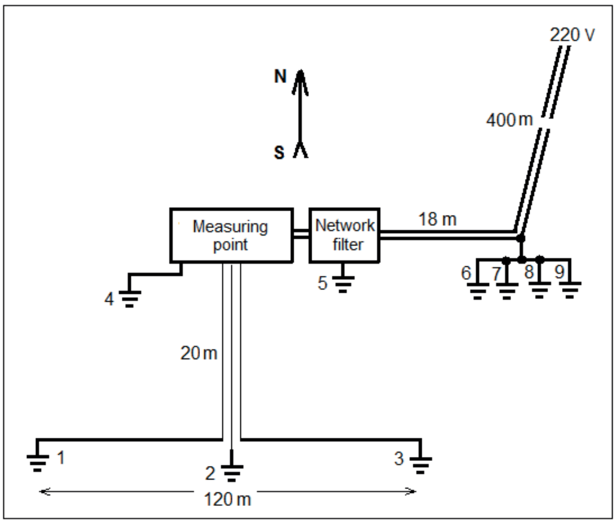
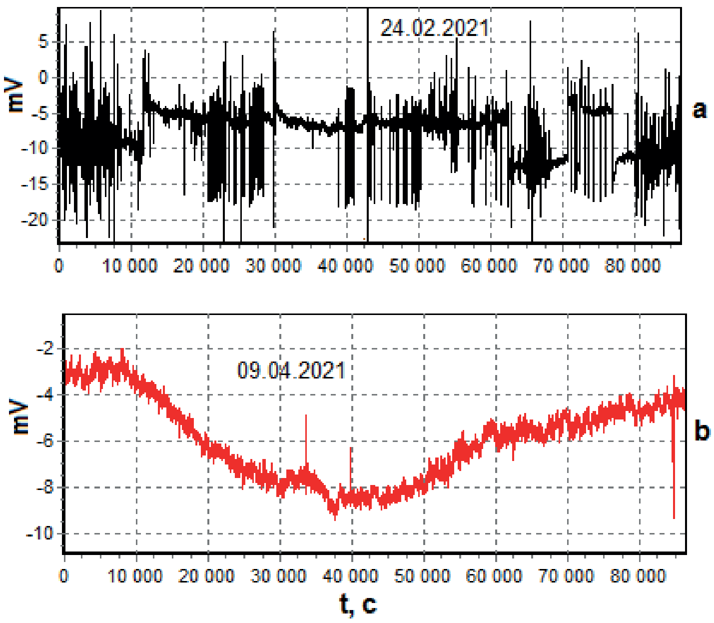


Figure 6 – Scheme of the grounding system of the measuring point

As it was said above, grounding electrodes 1 and 3, spaced 120 m from each other, are used to measure telluric current. The electrical signal from electrodes 1 and 3 (telluric current) is fed to the amplifiers of the recording equipment via a shielded symmetrical line (twisted pair) about 20 meters long. The electrodes 2 and 4 provide grounding of the thunderstorm protection system gas arresters. All these electrodes 1-4, made of lead 41x8x1 cm size, buried 1 m deep in the ground. In order to effectively suppress the impulse interference during lightning discharges, a network two-link LC-filter of lower frequencies grounded by a steel electrode 5 is installed at the inlet of the measuring station box.At distance 18 m apart from the measuring point the neutral wire of the power main is separately grounded using the steel electrodes 6–9 which are driven into the soil up to 1 m depth and electrically connected to each other. Thus, the spatial separation of the grounding systems of the telluric current recorder from the power main cable allows to almost completely exclude the influence of stray currents on the useful signal of telluric current.

It is important to note that in the case of connecting all grounding electrodes to one point, the measurement of telluric current variation will be practically impossible due to interference introduced by stray currents. This conclusion is illustrated by two examples of recordshown in Fig.7.



a – withinterferencefromstraycurrents, whenallthegroundingelectrodesconnectingtoonepoint;b – withoutinterference, withthespatialseparationofgroundingsystems.X-axis – time in seconds from the beginning of the day

Figure 7 – Daily recording of telluric current variation

Results and its discussion. Regular measuring of the telluric current variations started in spring 2021, and since that time some interesting effects has been found in the records of the telluric current.In the telluric current records,it is possible to observe the appearance of ULF oscillations corresponding to the periods of micropulsations of the geomagnetic field of Pc2 - Pc4 class(see Fig. 8), which represent relatively narrow-band oscillations of the geomagnetic field.

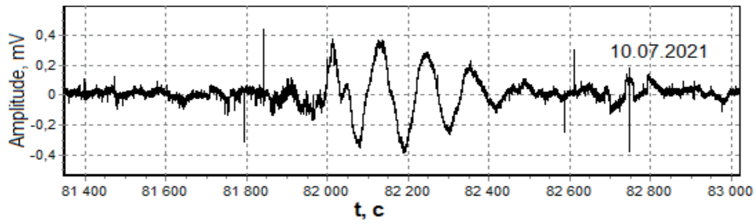
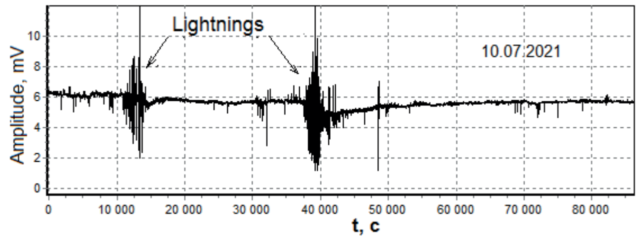


Figure 8 –The appearance a tsug of oscillations in the telluric current variation with a period about 115s.X-axis – time in seconds from the beginning of the day

Theoccurrence of geomagnetic field pulsations can be associated with earthquakes [13]. It can be assumed that the seismogenic electrical signals on the records of TC will be of much lower level than magnetospheric and, all the more, the thunderstorm signals.

Let us give an example of the appearance of pronounced bursts of telluric current at lightning discharges during near thunderstorms (Fig. 9).

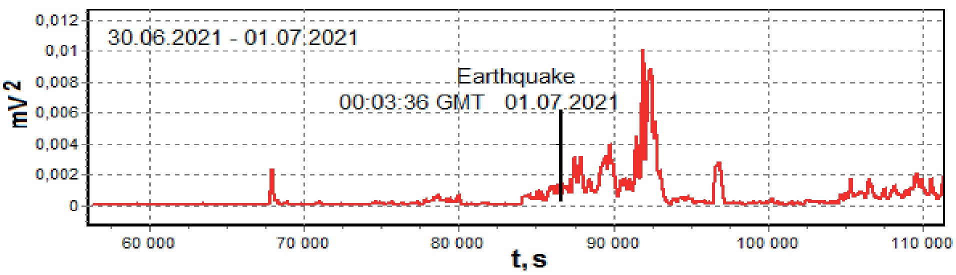


Arrows are marked the moments of lightning.X-axis – time in seconds from the beginning of the day.
Figure 9 – The effects of lightning discharges in the record of the telluric current.

The figure shows that during the thunderstorm and numerous lightning discharges, the receiving and recording equipment worked properly and the record of telluric current did not interrupt. This is an evidence of the effectiveness of the newly created system of lightning protection while operating in high-altitude mountain conditions.

The following example concerns earthquake response in telluric current records. According to the data of the seismic stations on July 1, 2021, an earthquake of magnitude MPV 4.5 K=9.3, depth 20 km occurred on the territory of Kazakhstan in 63 km east of Almaty cityand 60.4 km from the measuring point. The coordinates of the epicenter 42.92°N 77.67°E (some.kz).

On the eve and on the day of the earthquake there were no any interferences of the geomagnetic, anthropogenic or meteo nature. Under such «good weather» conditions, the calculation of the dynamic power spectrum of telluric current variation allowed us to reveal the response to the earthquake (Figure 10).



The moment of the earthquake is marked with a vertical line. X-axis – time in seconds from the beginning of the date June 30, 2021
Figure 10 – Response to M4.5 earthquake in the dynamic power spectrum of the telluric current variation

The dynamic power spectrum was calculated in the frequency range 0.2 Hz - 0.0282 Hz. The graph shows that just after the main shock a significant increase of the dynamic spectrum power of the telluric current relative to its background value has occurred. The absence of natural and industrial noise during this period allows us to suggest that electrical signals of seismogenic origin were recorded.

Conclusion. With the purpose to detect the seismogenic electric signals a special electronic equipment and software was created and put into continuous operation on the research center «Kosmostantsiya»which is situated in a seismically active region of the Zailiysky Alatau (Northern Tien Shan), near the foci of the Vernensky (M7.3) and Keminsky (M8.2) catastrophic earthquakes.

The new registration system allows for uninterruptible monitoring of the telluric current variation in the ultra low frequency range (0–20 Hz) and elaborated mathematical algorithms make it possible real-time analysis of the data on the eve and at the time of the earthquake.

To achieve reliable twenty-four-hour operation of the recording equipment a special means of thunderstorm protection and grounding system were designed and verified by practical exploitation under high mountain conditions.

The capabilities of the newly created equipment made it possible to detect both the weak electric signals with amplitude of several tens - hundred of microvolts only, and intensive electromagnetic pulses from close lightning without the damage of registering apparatus

The spatial separation of the grounding systems of the telluric current recorder from the circuits of the grounding system of power supply devices was performed, which made it possible to almost completely eliminate the influence of stray currents on the measurement of telluric current.

In the telluric current variation, the appearance of wave oscillations in the frequency range of micropulsations of the geomagnetic field of the Pc2 - Pc4 class, has been registered.

During an earthquake in the dynamic power spectrum of the telluric current in the frequency range 0.2 Hz - 0.0282 Hz, the electrical signals were revealed, presumably of seismogenic origin.

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ІЛЕ АЛАТАУЫНЫҢ СЕЙСМИКАЛЫҚ БЕЛСЕНДІ АУДАНЫНДАҒЫ ТЕЛЛУРИЯЛЫҚ ТОКТАРДЫҢ ВАРИАЦИЯЛАРЫН ЗЕРТТЕУГЕ АРНАЛҒАН АППАРАТТЫҚ-БАҒДАРЛАМАЛЫҚ КЕШЕН

Аннотация. Жер сілкіністерін дайындау процесінде сейсмоэлектрлік сигналдарды анықтаудың өзекті мәселелерін шешу үшін Верный М7.3 және Кемин М8.2 апатты жер сілкінісі ошақтарының жанында Іле Алатауының (Солтүстік Тянь - Шань) сейсмикалық белсенді өңірінде орнатылған ультра төмен жиіліктер диапазонындағы (0-20 Гц) теллуриялық токтың вариацияларын зерттеуге арналған аппараттық-бағдарламалық кешен құрылды. Теллуриялық токтың өзгеруін үздіксіз тіркеу және көрімдеу үшін алгоритмдер мен бағдарламалық жасақтама жасалды. Кезбе токтардың өлшеу жабдығына әсерін төмендетудің тиімді жүйесі, найзағайдан қорғаудың оңтайлы схемасы және жоғары найзағай белсенділігі кезеңіндеде үздіксіз өлшеулер жүргізуге мүмкіндік беретін электр қоректендіру құрылғыларының жерге қосу жүйесі ұсынылған. Теллуриялық токты өлшеудің аппараттық-бағдарламалық кешен жабдығына зақым келтірместен найзағай разрядтарының электромагниттік сигналдарын, сондай-ақ қабылдау құрылғысының кіре берісінде ондаған немесе жүздеген микровольт деңгейі бар әлсіз электр сигналдарын тіркеуге қабілетті екендігі көрсетілген. Теллуриялық токтың вариацияларында Pc2-Pc4 класындағы геомагнитті көрістің микропульсациялар жиілігі саласындағы толқындық тербелістер тіркелген. Жер сілкінісі қарсаңында және жер сілкінісі кезінде теллуриялық токтың вариацияларында сейсмогендік электр сигналдарын анықтау келешегі өлшеу пунктінен 60 км қашықтықта 2021 жылғы 1 шілдеде болған MPV 4.5 магнитудасы бар жер сілкінісі кезінде алынған деректер мен расталады. «Жақсы ауа-райы» және өнер кәсіптік кедергілердің төмен деңгейі жағдайында 0,2 Гц -0,0282 Гц жиіліктер аралығында теллуриялық ток вариацияларының динамикалық қуат спектрінде сейсмогендік шығу тегі бар айқын электрсигналдары анықталды.

Түйінді сөздер: аппараттық – бағдарламалық кешен, теллуриялық ток, сейсмогенді электрсигналы.

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АППАРАТНО-ПРОГРАММНЫЙ КОМПЛЕКС ДЛЯ ИССЛЕДОВАНИЯ ВАРИАЦИЙ ТЕЛЛУРИЧЕСКОГО ТОКА В СЕЙСМОАКТИВНОМ РАЙОНЕ ЗАИЛИЙСКОГО АЛАТАУ

Аннотация. Для решения актуальных вопросов обнаружения сейсмоэлектрических сигналов в процессе подготовки землетрясений создан аппаратно-программный комплекс, предназначенный для исследования вариаций теллурического тока в диапазоне ультранизких частот (0 - 20 Гц), который установлен в сейсмически активном регионе Заилийского Алатау (Северный Тянь-Шань) вблизи очагов Верненского М7.3 и Кеминского М8.2 катастрофических землетрясений. Разработаны алгоритмы и программное обеспечение для непрерывной регистрации и визуализации вариаций теллурического тока.Предложены эффективная система снижения влияния блуждающих токов на измерительное оборудование, оптимальная схема грозозащиты и система заземления электропитающих устройств, позволяющая проводить непрерывные измерения даже в периоды высокой грозовой активности. Показано, что аппаратно-программный комплекс измерений теллурического тока способен без повреждения оборудования регистрировать электромагнитные сигналы молниевых разрядов, так и слабые электрические сигналы, имеющие на входе приемного устройства уровень в десятки - сотни микровольт. В вариациях теллурического тока зарегистрированы волновые колебания в области частот микропульсаций геомагнитного поля класса Pc2 - Pc4. Перспективы обнаружения сейсмогенных электрических сигналов в вариациях теллурического тока накануне и во время землетрясений связаны с данными, полученными во время землетрясения магнитудой MPV 4.5, произошедшее 1 июля 2021 г. в 60,4 км от измерительного пункта. В условиях «хорошей погоды» и малого уровня промышленных помех в динамическом спектре мощности вариаций теллурического тока в интервале частот Гц 0,2 Гц - 0,0282 Гц в момент основного толчка были выявлены отчетливые электрические сигналы, предположительно сейсмогенного происхождения.

Ключевые слова: аппаратно-программный комплекс, теллурический ток, сейсмогенный электрический сигнал.

Acknowledgments. This work is supported by the grant code AP09260262»Monitoring and research of geospheric interactions in the lithosphere-atmosphere-ionosphere system in geodynamic active regions» of Ministry of Education and Science of the Republic of Kazakhstan. The authors are grateful to the management of the Tien Shan high-mountain scientific station of P N Lebedev Physical Institute of the Russian Academy of Sciences for support in organizing an experimental station for measuring the telluric current.

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ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)

Редакторы: *М.С. Ахметова, А. Ботанқызы, Д.С. Аленов, Р.Ж. Мрзабаева*
Верстка на компьютере *Г.Д.Жадыранова*

Подписано в печать 15.08.2021.
Формат 60х881/8. Бумага офсетная. Печать – ризограф.
4,6 п.л. Тираж 300. Заказ 4.

Национальная академия наук РК
050010, Алматы, ул. Шевченко, 28, т. 272-13-19