Research on Electronic Monitoring SystemsForThe Drilling ProcessIn Antarctic Conditions

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Abstract: - The article discusses the important topic of using electronic measuring instruments in the drilling process in the difficult conditions of Antarctica. It describes in detail modern methods and innovative technologies for protecting electronic equipment from aggressive environmental influences. The article also discusses the most effective protective measures designed specifically for drilling in the harsh Antarctic climate, ensuring reliable and accurate operation of instruments. In addition, an overview of various electronic systems, sensors, data acquisition devices, and control systems used in the drilling process is provided. To further develop this field, a detailed research plan has been developed to study and evaluate modern approaches aimed at improving the durability and efficiency of electronic devices in extreme conditions.

Key-Words: -Microelectronic, low-temperature, Antarctic, drilling, measuring systems, sensors

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1 Introduction

Antarctica, as a natural scientific laboratory, constantly attracts researchers from the world scientific community [1], [2], [3]. Scientists at the Mining University have been conducting experimental studies of glaciers and subglacial structures using drilling technology with great success. This technology and equipment are selected depending on the purpose of the study.

Drilling is complicated by many factors: complex logistics (transportation of metal structures and large amounts of fuel is very resource-intensive, and in some cases is completely impossible); difficult climatic conditions (pressure, temperature); unique natural environment: pollution or environmental disturbance can lead to irreversible consequences [4].

The dependence of measurement quality on extreme conditions determines the special requirements for the use of measuring instruments in an electromechanical drilling rig used by the Russian expedition.

To increase the efficiency and speed of drilling operations and accurate measurement of parameters, it is necessary to provide reliable methods and methods for protecting electronic equipment, in particular electronic measuring instruments.

Within the framework of this work, an analysis of modern methods and innovative technologies for protecting electronic equipment from harsh environmental influences such as extreme cold, humidity, and mechanical stress is carried out, and effective solutions and protective measures designed specifically for drilling in Antarctica are considered. Based on an overview of the various electronic systems used in the drilling process, it can be concluded that reliable operation of electronic equipment is an essential part of the correct operation of drilling equipment in Antarctica [5].

The objective is to investigate electronic systems for monitoring drilling in Antarctica. To do this, it is necessary:

– To study the protection of components from extreme temperatures, taking into account materials, coatings, and thermoregulation systems;
– Analyze the moisture protection and tightness of devices in conditions of high humidity and dust, considering traditional and new methods;
– Evaluate existing drilling monitoring technologies, their reliability, functionality, and data processing algorithms.

2 Scientific Achievements in the Field of Electronics Protection from Moisture and Harsh Temperature Conditions

The penetration of moisture into electronic devices, even in small quantities, can lead to serious consequences. In the article "Harmful effects of water on electronic devices," a group of American scientists described various ways moisture can enter electronics.

The main routes of moisture penetration include:

- Direct contact with water;
- Diffusion of water vapor into the environment and subsequent penetration through process openings, crevices, and microscopic leaks of the housing;
- Condensation of water vapor on surfaces or inside electronic devices, especially during sudden temperature changes when the device is transferred from a cold room to a warm one [6].

The main mechanisms of damage to electronic devices by moisture include:

- Formation of short circuits. Water, especially non-distilled water containing salts and impurities, is an effective conductor of electricity. When it hits the printed circuit board, it forms unintended conductive paths between the circuit elements, which leads to short circuits.
- Electrolysis and corrosion. In the presence of moisture and electrical potential differences, even when the device is turned off, and the battery is still connected, electrochemical corrosion of metal components begins, such as tracks on the printed circuit board. Contacts and terminals of components. Metalions pass into an aqueous solution, destroying conductive pathways. Over time, this can lead to an interruption of electrical circuits or a deterioration in the quality of electrical contacts.
- Oxidation of contacts. A humid environment significantly accelerates oxidation processes on metal surfaces, which leads to the formation of non-conductive oxide films. This reduces the reliability of electrical connections and may cause the device to malfunction.
- Degradation of insulation materials. Some dielectric materials, such as plastics and insulating varnishes, lose their insulating properties when saturated with moisture. Increasing the likelihood of electrical breakdown and current leakage;
- Mechanical damage to components. When moisture freezes inside the device, ice forms, which, expanding, can mechanically damage fragile components such as microcircuits and solder joints.

To protect electronics from moisture, preventive measures are required to help avoid moisture from entering the work area.

Preventive measures include careful selection of equipment with an appropriate degree of protection from moisture, which implies an analysis of operational characteristics and certification standards. It is also necessary to strictly observe the operating conditions, avoiding contact of the devices with liquids and maintaining optimal conditions of use.

There is a standard for the protection of electronic devices - GOST 14254-2015. At production facilíties or sites where electronic devices are located in close proximity to aquatic environments, devices made according to IP58 and IP69 standards (marked according to maximum liquid pressure) are used. To meet the requirements of these standards, the most common method is to use waterproof enclosures, but this method has a number of disadvantages, such as increased weight and size; increased complexity of maintenance and repair; risks of condensation; problems with cable leads and connectors: and pressure and depth restrictions. Polymer protective coatings, in contrast to the sealing of enclosures, are a more economical and less labor-intensive method [7], [8].

Polyparaxylene coatings, also known as parylene, are an innovative solution for protecting electronic devices from external factors.

These coatings are formed by vacuum deposition from the gas phase. This approach provides significant advantages over traditional methods of using liquid media. The coating process is carried out using specialized vacuum installations. The coating thickness is adjusted by changing technological parameters such as the substrate temperature and the monomer feed rate [9], [10].

One of the key advantages of polyparaxylene coatings is their high electrical insulation ability. The dielectric constant of the material ranges from 2.65 to 3.5, and the electrical strength reaches 500 kV/mm, which ensures reliable protection of electronic components.

In addition, parylene is characterized by low moisture and gas permeability, while water absorption is less than 0.1% in 24 hours. This property makes it especially useful when used in conditions of high humidity.

Polyparaxylene has a special chemical inertia. The material demonstrates high resistance to aggressive chemicals, which significantly extends the service life of electronic devices.

The coating also retains its properties over a wide temperature range. From 100°C to 150°C in the air and up to +400°C in an oxygen-free environment, which makes it suitable for use in extreme conditions.

The elasticity of polyparaxylene coatings is also worth mentioning.

The relative elongation of the material can reach 200%, which allows it to adapt to various product configurations and provide reliable protection even under mechanical stress.

It should be noted that polyparaxylene coatings do not significantly affect the thermal conditions of the equipment due to their small thickness and satisfactory thermal conductivity. This allows the use of parylene in highly integrated microcircuits, where traditional protection methods such as epoxy, silicone, and polyurethane coatings do not provide sufficient efficiency. [11], [12], [13].

Thus, the vacuum deposition method of polyparaxylene coating is an innovative solution in the field of electronic device protection, allowing the integration of high-performance protective coatings into complex engineering systems with a high degree of accuracy and reliability.

Most modern industrial microelectronic devices equipped with integrated circuits with submicron elements operate in the temperature range from -40°C to +70°C. This temperature range is due to the use of advanced semiconductor technologies in their design. In typical domestic and industrial conditions, the ambient temperature usually corresponds to the parameters set by the manufacturers of integrated circuits.

However, in some cases, it becomes necessary to operate electronic products in more extreme temperature conditions.

At elevated temperatures, degradation of electronic components is observed, and when temperatures exceed the melting point of materials used in integrated circuits or crystals, a complete or partial violation of their functional characteristics is possible [14]. In addition, the risk of short circuits due to thermal damage to the contact pads increases, which can lead to fire-hazardous situations.

Low temperatures, although they pose less of a threat to electronic devices, have a significant impact on their performance and reliability.

Extreme temperature conditions can significantly reduce the efficiency of electronic components and increase the likelihood of failures, which requires the use of specialized thermal stabilization and protection methods [15].

The oil and gas industry has telemetry power solutions based on lithium-ion (Li-ion) batteries.

Lithium-ion (Li-ion) batteries are a key power source for a wide range of electronic devices due to their energy characteristics and high power density. However, in order to ensure optimal performance and safe operation of these batteries, it is necessary to strictly control the operating temperature conditions, ranging from 20°C to 55°C. Exceeding the temperature threshold of 55°C can lead to a decrease in battery capacity [16] or even to undesirable thermal effects, including thermal acceleration, which, in turn, can provoke fires and explosions [17], [18].

On the other hand, low temperatures also have a negative effect on battery parameters. In particular, a decrease in temperature causes a deterioration in the conductivity of the electrolyte [19] and a slowdown in the diffusion of lithium ions [20]. These factors lead to a voltage drop at the battery terminals and irreversible loss of capacity [21], [22].

Supercapacitors can be used as an alternative power source. Due to their high energy density and the ability to quickly charge and discharge, they are an alternative to traditional rechargeable batteries. Supercapacitors are highly resistant to temperature fluctuations, which allows them to be used in various energy sectors, including renewable energy sources, transportation systems, and industrial applications. Their integration into power supply systems is a promising area that significantly improves the reliability of uninterruptible power supply at extremely low temperatures. This step opens up new opportunities for optimizing energy processes and increasing the resilience of systems to an unfavorable climate [23], [24].

Thus, the integration of supercapacitors into power supply systems represents a promising technical solution that contributes to improving the reliability, efficiency, and stability of energy systems in extreme temperature conditions [25], [26].

The integration of polyparaxylene (PPK) protective coatings with supercapacitor systems represents an advanced and innovative approach to solving.

Fundamental problems related to the functioning of electronic devices in the extreme conditions of Antarctica. This method can significantly increase the reliability and durability of equipment, which is critically important for ensuring efficient operation in conditions of extremely low temperatures, high radiation background, and extreme climatic factors.

2.1 Modern Drilling Technologies in Antarctica

Drilling operations in Antarctica are exposed to a number of unique and complex factors related to extremely low temperatures both on the surface and inside glaciers, as well as the lack of a developed transportation and infrastructure system. Severe climatic conditions, including gale-force winds, heavy snowfall, and other meteorological phenomena, significantly complicate scientific research. Traditional rotary drilling rigs designed for core sampling from glacial deposits have a significant mass and high capacity, which limits their adaptation to the specific conditions of the continent [27].

To overcome the above-mentioned difficulties, specialized electromechanical drilling rigs with a rope suspension system designed for drilling deep wells in Antarctica have been developed. A key component of this technology is the method of lowering and lifting drilling equipment into and out of the well. Unlike traditional rotary drilling rigs, where mechanical energy is transferred through a pipe system to destroy rocks and extract core samples, electromechanical rigs use a borehole unit, an armored cable, and a winch [28].

This approach ensures high efficiency and reliability of drilling in the extreme conditions of Antarctica, allowing for research at significant depths with a high degree of accuracy.

Thus, the development and implementation of specialized electromechanical drilling rigs represents significant progress in the field of glacial sediment drilling and are an important step in expanding the possibilities of scientific research on the Antarctic continent [29].

Currently, the latest developments are being used by researchers at Jilin University in China, as well as by Russian and American Antarctic expeditions [30], [31].

Chinese engineers have developed an improved version of an electromechanical drilling device with a cable suspension, designed for drilling in fir ice, glaciers with inclusions of debris and rocks. This innovative system consists of two main components: an upper and a lower one, each of which performs specific functions [32], [33].

The upper part of the drill, universal for all modifications, includes four key sections: a cable tip, a contact ring system, a device for compensating the reactive moment, and an electronic pressure chamber. The lower part of the drill consists of a screw drill, expansion elements, a specialized drill for working with glaciers and inclusions, as well as a standard geological drill with a single-tube column or, in some cases, a custom-made double-tube drill with a column [34].

In the research conducted by scientists from Jilin University, special attention is paid to a modified cable containing synthetic material. This innovative approach significantly improves the operational characteristics of the drilling rig, ensuring its reliability and efficiency in various geological and geographical conditions [35], [36].

In modern scientific and technical research, there is an active development of technologies for drilling glaciers to access subglacial waters using heating methods. Chinese scientists presented the results of testing an innovative autonomous probe (RECAS) designed for measuring operations and sampling in subglacial reservoirs in their work "Extractable autonomous probe for exploring subglacial lakes: development of an electronic control system." This tool ensures the isolation of sublacial lakes from the atmosphere and the surface of the glacier, which is crucial for the conservation of ecosystems and the prevention of pollution.

The article examines in detail the development of an electronic control system for the 200-meter prototype RECAS. The system includes three key components: a ground control system (NMS), a borehole control system (DBMS), and an energy and data transmission system (EDMS). Special attention is paid to the SUBS, which provides monitoring of the probe's condition, control of its movement, sampling of sublacial water, and on-site analysis. To ensure the compactness and efficiency of the system, a specialized temperature sensor with an RS-485 interface has been developed, capable of operating in the extreme conditions of Antarctica.Humidity measurement methods were used to identify potential leaks in the probe body, as standard methods for monitoring water conductivity may be ineffective due to the low mineralization of subglacial waters. The water sampler control board has been designed to precisely control the activation and deactivation of sampling mechanisms. The high-resolution camera system, equipped with a built-in storage and self-heating function, provides high-quality video shooting in sublacial reservoirs.

The tests confirmed the effectiveness of the proposed electronic control system, which indicates its reliability and prospects for further research in the field of subglacial hydrology and ecology [37], [38].

The American Arctic Expedition also has high-tech drilling rigs for deep drilling. The most advanced of them from the point of view of electronic measuring equipment is a core re-sampling unit: the core re-sampling control system performs two main functions: positioning the drilling rig in the required coordinates and correcting this position by controlling it and executing operator commands. The core re-sampling control system consists of several key components, including adjustable DC stabilizers, a drilling rig power supply, as well as ground and on-board computers [39].

Six levers (three for each drive section) are used to deflect the drill bit. Each of the levers is powered by a motor with a feedback controller for each motor. This requires the control of six independent axes. To deflect in the required direction, two of the three levers in each drive module must be moved correctly in order to direct the necessary forces from the levers to deflect in the correct azimuth. The rig operator can enter the azimuth, as well as the amount of force applied to the levers. The design of the control system allows the drill bit to easily create the necessary force on the borehole wall with minimal operator intervention [40], [41].

The Russian expedition uses a KEMS-132 drilling rig (Figure 1). This drilling rig has proven to be one of the best solutions for drilling in Antarctica. It was used to drill the deepest well in the region [42].

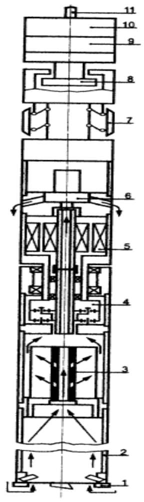

Fig. 1 – KEMS-132 Electromechanical Drill: 1 - drill bit, 2 - drill pipe, 3 - slurry filter chamber, 4 - gearbox, 5 - drive electric motor, 6 - pump, 7 - counter-torque system, 8 - impact block, 9 - electric chamber, 10 - cable suspension bracket, 11 - cable [43].

This electromechanical projectile, developed at St. Petersburg Mining University, has demonstrated high efficiency, which made it possible to successfully open the subglacial Lake Vostok in 2012. The innovative design of the KEMS-132, which includes an electromechanical core module, operates on the basis of a load-bearing cable, which significantly reduces the weight of surface equipment and optimizes the processes of descent and ascent. The power supply and control system is adapted to extreme operating conditions, including temperatures up to -60°C and pressures up to 40 MPa, which ensures stable operation in harsh Antarctic conditions [42].

During drilling operations, a specialized filling liquid was used, which is a mixture of kerosene and freon F-141b with a density of about 928 kg/ m3. Maintaining the level of this liquid at a depth of 40 m in the borehole minimized the pressure gradient between the rock ice pressure and the hydrostatic pressure of the liquid at the bottom, which was about 0.1 MPa. This prevented the borehole from narrowing and ensured stable drilling.

Using KEMS-132, the 5G well was successfully deepened from 2,755 m to 3,623 m over several seasons between 1995 and 1998. In 2012. The Vostok subglacial reservoir was reached at 3,769.3 m, which was a significant world-class achievement.

The lake was opened using a special technology, including filling the lower 100-meter interval with buffer liquid, then drilling the last 30 meters with a thermal drill projectile, freezing the rising lake water, and drilling the formed ice to extract the core. This comprehensive approach made it possible to successfully complete the tasks set and obtain valuable information about the subglacial Lake Vostok.

Currently, scientific research is aimed at improving drilling technologies. In particular, experiments are being conducted with the use of cyclone filters to increase the efficiency of cleaning from ice sludge. In addition, dynamically balanced drilling systems with complex reciprocating motion kinematics are being developed, designed for operation in conditions of increased complexity.

Electronics play a key role in the design of the KEMS-132 drilling rig, which ensures control of the drilling process and maintenance of the system's operability in extremely difficult conditions. The main elements of the electronic systeminclude:

- A drive electric motor that transmits rotational motion to the crown by means of a gearbox. The electric motor is powered by a 220-volt mains supply.
- An electrical compartment with a cable connector through which electricity is supplied via a load-carrying cable. Current collectors, step-down transformers, and other elements of electrical equipment can be placed in this compartment.
- A control system that includes sensors and controllers for monitoring key drilling parameters, such as rotation speed, bottom-

hole load, and circulating fluid characteristics [2], [43].

To ensure reliable operation at low temperatures and high pressure, the electronics of the KEMS-132 drilling rig must have a high degree of protection and resistance to external influences. This requires the use of specialized materials and innovative design solutions.

3 Ways to Protect Electrical Equipment During Well Drilling in Antarctic Conditions

Currently, all drilling rigs used in Antarctic research projects are equipped with thermally sealed chambers to accommodate electronic equipment designed to monitor and control the parameters of the drilling process. These chambers are critically important for ensuring the stable operation of electronics in the extreme conditions of Antarctica, ensuring the maintenance of an optimal microclimate, protection from mechanical influences and vibrations, as well as preventing the penetration of foreign particles and moisture.

The effectiveness of this technological innovation is confirmed by long-term practice. Automatic regulation of the climatic conditions inside the thermal chambers allows them to use more cost-effective electronics that were not designed to work in extreme conditions. This approach significantly reduces costs and increases the reliability of the equipment.

In addition, the use of electronics in the deep drilling process is of significant importance for geophysical research, which provides valuable data on the physical characteristics and structure of ice masses [44].

Currently, specialized downhole glacier monitoring devices equipped with 3D accelerometers and 3D magnetometers have been developed. These devices were used to carry out kinematic measurements of the ice velocity on the Jarvis Glacier located in Alaska [45], as well as to determine the profile of ice sheet deformation by analyzing data on the slope of wells on the Stor glacier located in Greenland [46], [47].

The Polar Research Center of Jilin University has developed a new borehole logging machine designed for operation in extreme conditions with extremely low temperatures and high pressures. This innovative device provides comprehensive monitoring of various well parameters. Including measuring temperature, pressure, tilt, azimuth, oriented diameter, and cross-section, as well as the borehole profile [48], [49].

In order to protect electronics from the negative effects of the environment, in particular from moisture, the most common method is to seal the case. This approach effectively prevents direct contact with water, but its effectiveness is significantly reduced with prolonged exposure to high humidity (Figure 2) [50], [51].

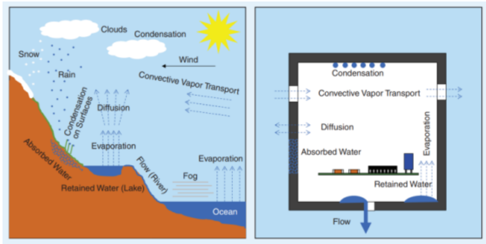

Fig. 2 - The hydrological cycle in nature compared to moisture transfer in electronic enclosures [52].

The growing importance of moisture-related problems in electronic devices is due to a combination of a number of factors, including technological miniaturization and the economic availability of electronic devices. As a result, these devices are becoming more widely used in various fields.

Typical examples of such devices are mobile phones and hearing aids. The miniaturization of electronic circuits leads to a decrease in their resistance to corrosion caused by exposure to moisture. Reducing the interconducting distances increases the electric field, which contributes to the development of electrochemical corrosion and migration of materials [52], [53].

These phenomena pose a significant threat to the reliability and durability of electronic systems, especially in conditions of high humidity. Solving this problem requires the use of integrated approaches, including the development of innovative materials, methods of protection from moisture, and optimization of technological processes for the production of electronic components. Optimization of energy consumption helps to reduce the level of heat generation in electronic circuits, which allows them to be kept dry.

Of particular difficulty is the problem of thermal contact of electronic devices with surfaces whose temperature is lower than the ambient temperature. Such surfaces are subject to a continuous process of condensation of water vapor, which leads to exposure of electronic devices to humidity equivalent to water.

Packaging methods that limit the maximum temperature and its fluctuations when switching on/off the power supply have proven their effectiveness [54], [55]. It is still important to understand and take into account such loads. In contrast, the effects of moisture are usually not fully understood by design engineers. Problems are often solved by making last-minute corrective changes rather than by early detection and careful selection of design strategies.

As a result, end users often find that insufficient resistance to climatic influences does not allow them to fully use an electronic device or even leads to an unsatisfactory level of quality [56], [57].

One of the key tasks in ensuring the tightness of enclosures is to solve the problem of sealing process openings, which is a complex engineering task. In cases with a typical design and mechanisms that allow moisture to enter, these holes can occur either intentionally or accidentally.

Intentional openings, such as ventilation openings for temperature control and drainage openings for moisture removal, serve as an important functional element. However, unintended openings, including imperfections in the seals between the housing and the lid, cable entries, as well as microcracks and pores in durable materials, can significantly impair the tightness of the structure.

Moisture transfer through these openings can occur through various convection mechanisms: forced, natural, or so-called "breathing."

Diffusion transfer of moisture is also carried out through porous materials. Liquid water is able to enter and exit through these openings, provided that surface tension does not interfere with its movement [57].

4 Conclusion

It is proposed to use modern methods of protecting electronic components from moisture and temperature to increase the reliability of measuring instruments. In order to select the most effective and optimal solution, it is planned to conduct research on advances in this field using refrigerating chambers and laboratory drilling rigs.

The study is planned to be divided into the following stages:

- Investigation of the behavior of microelectronics at low temperatures and various humiditylevels in the absence of protection.
- Investigation of the behavior of microelectronics under the same conditions with hermetically sealed heated enclosures.
- Investigation of the behavior of microelectronic products under the same conditions with applied polymer coatings. Studies should be conducted using various types of coatings, including their combinations.
- Analysis of sensor readings and electronic operability.

At the first stage of the practical part, the experiments will include measurements of sensors A located on the control module in the refrigerator compartment. The control module includes a microcontroller with a connected set of sensors, covered with a polyparaxylene film. The power source in the form of a battery of supercapacitors will also be located in the refrigerator in the immediate vicinity of the control module.

Connected sensors:

- Vibration sensor;
- Torque sensor;
- Axial load sensor;
- Thermometer;
- Humidity sensor;
- Barometer.

Readings of the voltage drop of the supercapacitor unit will also be taken when the temperature drops over time.

The refrigerator compartment has the following characteristics:

- Temperature range: from +20°C to -60°C.;
- Temperature maintenance accuracy: ÷0.5°C;
- The volume of the working area is 1m3:
- Ventilation system;
- Viewing window;
- Ports for cable input/output.

At the second stage, studies of the most effective methods will be conducted on a laboratory drilling rig.

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