PRINCIPLES OF MODULAR ASSEMBLY AND DUAL-REDUNDANCY DESIGN FOR INTERNAL ELECTRONIC COMPONENTS OF GEOPHYSICAL PROBES OPERATING UNDER EXTREME HYDROMECHANICAL AND THERMAL LOADS

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Abstract. *This scientific article investigates novel design methods for the internal electronic control and sensor systems of measurement probes operating under severe hydrostatic pressure, high temperatures, and high dynamic shock loads within deep exploration and directional drilling wells. To enhance the device's survivability rate and field-maintainability, structural design solutions were developed. These include a modular assembly architecture, a dual-redundant 9-axis inertial sensor system operating independently, an explosion-proof lithium iron phosphate ($LiFePO_4$) power supply, and a microsystem for remote online software/firmware updates.*

Keywords: *Modular assembly architecture, dual-redundancy, dual inertial sensor, lithium iron phosphate battery, power control sensor, remote online firmware, hydraulic housing, shock resistance.*

Introduction and problem statement. Downhole geophysical measurement probes and inclinometers operate in some of the industrial sector's most extreme and destructive environments during and after the drilling process. The device housing and internal microcircuits must withstand immense hydrostatic pressures up to 30 Megapascals (at depths of approximately 3,000 meters), geosynchronous temperature rises up to +75°C (and sometimes higher), and sharp mechanical shocks up to 50g (with a duration of 0.5 milliseconds) caused by the drill string impacting rock formations. The greatest disadvantage of current foreign equipment used today is that their internal electronic circuit boards are built as a single monolithic structure.

In such circuits, the detachment or burnout of even a single small transistor or sensor element due to mechanical shock leads to the complete failure of the entire expensive equipment. Due to the lack of foreign service centers in our republic, importing spare parts and experts from abroad (such as the United Kingdom) to repair the equipment or fix errors in its software causes months of delays and immense financial losses.

Structural solutions and engineering architecture. To eliminate this technological dependence and systemic downtime, this project proposes, for the first time, the design of geophysical probe microcircuits based on the principle of "modular assembly." The internal electronic circuit board is divided into separate functional block-modules connected via high-durability, specialized industrial connectors. The system architecture consists of the following independent modules: a central computing and dual memory card module, two absolutely independent 9-axis inertial measurement sensor modules configuration (primary and redundant), a power and smart power control module, and a universal adapter module communicating with external natural gamma-ray background and acoustic sensors.

The circuit boards are mounted onto an internal chassis made of a monolithic aluminum-titanium alloy and enclosed from the outside within a hydraulic protective shell featuring two-layer hermetic (O-ring) seals. For the energy system, lithium iron phosphate ($LiFePO_4$) - type 32700, 6000 mAh) batteries were integrated, which are free from explosion and combustion hazards during drastic downhole temperature changes and provide stable voltage across a wide temperature range. A power control sensor incorporated into the microsystem measures the battery capacity in real time and transmits digital warning signals to the surface.

Technical advantages and practical application. The modular assembly and dual-redundancy system mathematically increase the reliability metrics of the equipment. If the primary 9-axis sensor is damaged due to a severe shock during field measurements, the central processor activates the backup sensor within microseconds to prevent system downtime. It continuously backs up the acquired data in parallel onto two independent micro-SD memory cards in both binary (BIN) and text (TXT) formats. If a physical fault occurs in any module block, the logging operator can pull out only the faulty module and replace it with a new one in just 5 minutes, without replacing the entire circuit board. Most importantly, a remote online software installation module at the microcontroller level has been integrated into the device, enabling our engineers at the central laboratory in Tashkent to remotely flash and diagnose the equipment's software algorithms in remote desert areas via the internet.

Conclusion

The development of the equipment's hardware and structural components using a modular and dual-redundant configuration establishes a new technological school in the field of domestic geophysical instrumentation. Furthermore, it drastically reduces operational costs and fully guarantees the continuity of well exploration workflows.

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