Feature Article: SQUID Applications  · Medical Applications

- Application of SQUIDs for Minerals Exploration

Tsunehiro Hato, Senior Research Scientist
Electronic Devices Division
SRL/ISTEC

Between 2010 and 2011, the author’s group developed a practical SQUID system applicable to minerals exploration under the development of the next generation SQUITEM equipment and SQUID magnetometers, commissioned by Japan Oil, Gas and Metals National Corporation (JOGMEC). With the successful completion of final tests in Australia, a practically designed SQUID system developed for electromagnetic exploration has been delivered to JOGMEC. This project was a joint development between ISTEC, who led the development of a magnetometer comprising of a SQUID sensor, and Mitsui Mineral Development Engineering Co., Ltd., who was responsible for fabricating the receiving apparatus.

In the TEM or electromagnetic method as shown in Figure 1, a copper-wire transmitter is positioned in a 100-200 m square and direct current applied. The current flowing through the transmission loop is abruptly turned off, which induces an underground current. By utilizing a highly sensitive magnetic sensor and measuring changes in the resistance of induced current differentiated by time, allows a distribution of sub-surface resistivity structure to be analyzed. For example, taking measurements every 100m builds a 2D picture of specific underground resistances that can be further investigated. SQUIDs are applicable to this methodology because of their high sensitivities, DC operational characteristics and wide frequency bands that range to 100 kHz. With exploration depths expected to reach 1km, a reliable system is required to handle large currents and the accompanying large magnetic field changes. Key developments to address these areas are dependent upon realizing operational system stability and high slew rates (the maximum rate of magnetic field change per unit time). Minimizing or eliminating RF noise is important to realize operational stability. Additionally, the induced currents generated within the system need to instantaneously attenuate at a rate fast enough so that sub-surface induced currents do not interfere with the magnetic field measurements. The author and his group have selected own materials to solve shield issues whilst researchers around the world continued racking their brains. The efforts have resulted in both operational stability and greater measurement accuracy. Cooling SQUIDs amidst terrestrial magnetism have led to the design of a structure suitable for field use, where the design was prioritized with wire filament technology in order to minimize flux trapping.
The system developed has achieved 10.5 mT/s slew rate characteristics, equivalent to 10-times the slew rate compared to conventional JOGMEC systems. The maximum current that can be applied has improved by over 40-times. This compact practical system is shown in Figure 2. The receiver system has a battery source that enables 17-hours of operation. Two attaché cases house the receiver system and magnetometer, including a 30 m-long cable that connects the receiver and magnetometer, which combined weigh a total of only 25.6 kg. Liquid nitrogen can be sustained for 17 hours if kept still and has been confirmed as offering more than required 8 hours of successful field operations, which includes its transportation.

Figure 3 shows the comparison between the analyses of testing trials of the distribution of underground resistivity structures measured in Akita. These results have proven that the system developed was able to analyze resistivity structures with greater resolution than systems utilizing induction coils and conventional systems employed by JOGMEC. The near-surface resistivity is greater, and here, the magnetic field attenuates rapidly when the applied magnetic field is artificially shut down. The induction coil and the system are both able to track the changes. A conventional system has insufficient slew rate and is therefore unable to respond to such changes. The induction coil reaches its detection limits at around an area 500m below the surface, resulting in greater uncertainty of measured resistivity structures. The system developed is clearly able to respond to increases in specific resistivity, overcoming the deficiencies of a conventional system. The reason behind such deficiencies is thought to be due to a disruption of measurements caused by an induced current generated within the system, attributed to the shutdown of the artificial magnetic field. Induced currents generated within a conventional system are not an impediment to analyzing areas exhibiting relatively lower specific resistivity, thereby allowing them to be effectively employed in the field. However, conventional systems are still predicted to influence the analysis of specific resistivity distributions measured in areas having high specific resistivity. The system developed here is expected to benefit measurements in areas where specific resistivity is high. Its high slew rate characteristics and the suppression of induced currents allow the system greater sensitivities and enable a continuous analysis of resistivity structures measurements 1km below the surface.
Final tests in Australia have analyzed 2D-like resistivity structures, produced by analyzing the data measured every 100m. The system even proved to be satisfactory when operating in environmental surface temperatures exceeding 50°C, providing precise measurements of the depth of low specific resistivity layer, including graphite located close to the surface. Additionally, the system was able to capture strata deeper than boring surveys, which are presumed to be rich in copper and iron. These findings clearly illustrate the significant advantages afforded by the TEM method, providing data from deep underground strata and its practical use in future exploration is highly anticipated.