

Development history of novel MT equipment using MI sensor

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SUMMARY

The magnetotelluric (MT) method is an electromagnetic exploration method that uses natural electromagnetic field variations to estimate the resistivity structure of the subsurface based on the ratio of the electric and magnetic fields. The MT method is used for geothermal exploration, mineral resource exploration, and petroleum exploration. Furthermore, the MT method's ability to probe deep subsurface has been utilized in geophysical studies of the crust and mantle. The Exploration Geophysics Laboratory of Kyushu University has been developing an electromagnetic measurement system for more than a decade for subsurface resource exploration and monitoring subsurface fluids (Mizunaga and Tanaka 2010; Mizunaga and Tanaka 2015). The results of this research have been recognized by the Japan Organization for Metals and Energy Security (JOGMEC), which has contracted us to conduct a two-and-a-half-year research project entitled "High-efficiency High-density Exploration Technology - Advanced MT Exploration Technique Using Small and Lightweight Equipment" under the contract with JOGMEC since FY2021. The main objective of this project is to "develop a compact and lightweight MT measurement system," as the research title indicates, but the project also includes many related studies. A feature of the new MT system, which differs significantly from conventional MT equipment, is that it uses magneto-impedance (MI) sensors instead of induction coils. MI sensor is a new compact sensor based on the magneto-impedance effect, which has excellent magnetic sensitivity, especially at low frequencies. Another major feature is using the SoC-type IC in the control circuit to reduce power consumption. Low power consumption enables continuous observation for 1-2 weeks, which was impossible with previous instruments. This paper provides an overview and history of the novel MT project.

Keywords: MT method, MI sensor, SoC-type IC, Low power consumption, Novel MT project

INTRODUCTION

The MT method is an electromagnetic survey method that utilizes the natural electromagnetic field perturbation caused by solar wind and lightning. The MT method has been used worldwide for subsurface and geothermal resource exploration, especially in Japan, and is used in many geothermal areas as a standard geophysical method.

However, conventional MT equipment is too heavy, especially the induction coils used for magnetic sensors, which account for most of the weight of the entire survey system. The weight of the induction coil makes it difficult to work in the geothermal field, leading to high exploration costs. In addition, induction coils have poor sensitivity to low-frequency magnetic fields, so low-frequency electromagnetic fields related to deep information are not always accurately measured. In addition, conventional equipment consumes much electric power, making it unsuitable for long-term continuous observation.

To solve these and other problems of the conventional MT survey, we upgraded the MT survey system in terms of both hardware and software. A feature of the new MT system, which differs significantly from conventional MT equipment, is that it uses magneto-impedance (MI) sensors

instead of induction coils. MI sensor is a new compact sensor based on the magneto-impedance effect, which has excellent magnetic sensitivity, especially at low frequencies.

This research project continued from FY2021 to FY2023. During the research period, two main prototypes using MI sensors were developed. One compact "all-in-one type" includes a 3-axis magnetic sensor with three MI sensors in the measurement body. The weight of all-in-one type equipment is less than one kg. The other is a "high-precision measurement type" with independent 3-axis magnetic sensors. This equipment's magnetic and electric sensor modules are designed to be mounted externally to avoid noise contamination to the measurement circuit.

We developed compact and lightweight prototypes for the MT survey step by step and investigated their performance. The next section provides an overview of the prototypes and their specifications.

OVERVIEW OF THE NEW MT SYSTEM


Generally, the development of a measurement system is considered to require many years. Therefore, we designed and built three prototypes with different configurations simultaneously to develop the system effectively within a limited time.

This section describes the characteristics of the three prototypes of MT exploration. In common with the three types of MT prototypes developed (Types A, B and C), MI sensors manufactured by Aichi Steel were used to measure the magnetic field, and a significant reduction in size and weight was achieved. In addition, considering measurements in mountainous areas with poor accessibility, we deployed many measurement devices equipped with inexpensive communication modules in the target area and configured a wireless mesh network to enable remote control of all the measurement devices. Using an MI sensor and a control circuit by an SoC-type IC reduced power consumption significantly.

While the continuous observation time of the conventional machine was about two days at best, the prototypes proved capable of constant measurement for 1-2 weeks. We also measured the prototype continuously for one week in the actual field.

The main features of MT prototypes from FY2021 to FY2023 are shown in Table 1. Within the limited period, we developed eight prototypes except B3. These measuring instruments are tested for performance in field surveys at geothermal areas and are improved yearly. The magnetic field sensor has been improved yearly in terms of frequency bandwidth so that high-precision MT surveys can be conducted.

Table 1. Main features of MT prototypes from FY2021 to FY2023.

	FY2021 1 st Prototypes	FY2022 2 nd Prototypes	FY2023 3 rd Prototypes
Development Goals Common Goals	Three types of equipments	Magnetic field sensors For low-frequency Highly stable measurement circuits	New magnetic sensor Expanded operating temperature (-10 to 40°C) Low power consumption Low noise and high stabilization circuit
A : Small type All-in-one	A1 Built-in magnetic sensor High-speed sampling	A2 Low Frequency by Electronic Circuit	A3 Reexamination of components and electronic circuits Measurements by frequency band (Continuous sampling)
B: Trial type Magnetic field sensor separation	B1 Modular Structure Various Power Supplies	B2 Cancellation of Earth's magnetic field components by Helmholtz coils	 Design based on trial results (control, power supply, amplification and filters)
C: High-precision type Separate electromagnetic field sensor and communication function	C1 High-precision measurement circuit Low noise circuit	C2 Low Frequency by Electronic Circuit	
Specification of magnetic sensors (MI sensor)	Commercially available (0.1 Hz to 1 kHz)	Modified commercial product (0.001 Hz to 1 kHz)	New type (DC to above 10 kHz)

DEVELOPED LATEST MT SYSTEMS

Figure 1 shows the latest MT prototype developed in FY2023. The A3 is the all-in-one type for mobile convenience. A three-axis magnetometer is installed in the main body. The maximum sampling rate is 1 kHz, and time-series data can be stored in an SD card. The detailed measurement functions for A3 are listed below.

- (1)Power connection terminal: Connects to 12V battery
- (2)Power button: Turns power on/off
- (3)LED Indicator: Indicates equipment status
- (4)Voltage input terminal: Connect wires for electric field measurement (2 lines)
- (5)Ground terminal: Connects ground wire

- (6)Antenna: For wireless communication (waterproof)
- (7)Vent: Suppresses condensation
- (8)USB terminal: For supplying power from mobile battery, Type-C cable connection (waterproof)
- (9)SD card outlet: Waterproof with rubber cover during measurement

Figure 2 shows the photos of prototype C3 (high-precision type) from different sides. In the case of the high-precision type, the electric module and magnetic module can be connected from outside using a sealed cable. The C3 can avoid the self-noise from the electric and magnetic modules. Figure 3 shows the electric and magnetic modules for C3. The electric module has the function of a pre-amplifier to detect weak signals. Since the latest A3 and C3 prototypes have just been

completed, we have not been able to carry out measurement experiments in geothermal areas, although operation checks have been completed. However, we have completed the experiments in the actual geothermal field for the prototypes (A2 and C2) from last year. An example of the measurement data is shown in Figure 4.

This figure compares the magnetic fields in two places (Yufu and Kanoya). This figure shows that the changes in the three magnetic components are very similar, indicating that the low-frequency magnetic field can be measured without problems.



Figure 1. Photo of prototype A3 (All-in-one type in FY2023).



Figure 2. Photos of prototype C3 (High-precision type in FY2023) from different sides.



Figure 3. Photos of the electric sensor module (upper) and magnetic sensor module (lower) for C3.

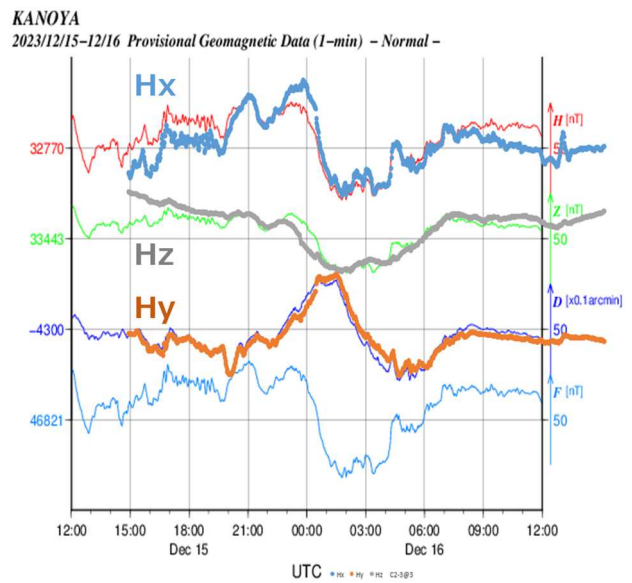


Figure 4. Comparison of low-frequency magnetic field. The three components of the magnetic field (averaged time-series over a period of about 82 seconds acquired in 2023 by C2) at station No. 3 in Yufu, Oita prefecture, Japan, and the magnetic field variation during the same period (sampling interval of 1 minute) measured with a fluxgate magnetometer at the Kanoya Observatory of the JMA Geomagnetic Observatory, Kagoshima prefecture, Japan.

CONCLUSIONS

We have developed prototypes of MT measuring instruments to improve the accuracy of geothermal exploration, which is the important key to promoting geothermal development. Using these prototypes,

we plan to conduct a test survey in actual fields in geothermal areas.

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