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AN AUTOMATIC ASTATIC MAGNETOMETER FOR PALEOMAGNETIC STUDIES

by

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(with 7 text-figures and 1 table)

Abstract

A computer controlled automatic astatic magnetometer system is developed at the paleomagnetic laboratory of the Department of Geology and Mineralogy, Hokkaido University. The main objects of this development are to obtain reliable magnetic directions from very weakly magnetized samples such as sediments and sedimentary rocks and to achieve an automatic instrument of rapid and multi-range measurements for various type of rock samples. A description of this system and the results obtained in testing the performance are briefly given.

Introduction

In paleomagnetic studies it is necessary for measuring the very small magnetic fields associated with the remanent magnetization of sedimentary and igneous rocks. And it is also necessary for a large number of measurements to obtain reliable mean direction of magnetization and is to reduce the time of a single measurement to a minimum.

Two methods have been developed to get high sensitivity for the study of the natural remanent magnetization (NRM) of weakly magnetized rocks. These are the astatic magnetometer and the spinner magnetometer. Most of the report on the astatic magnetometer emphasizes the high sensitivity and the high signal to noise (S/N) ratio of these instruments (Collinson and Creer, 1960; Collinson, 1966; De Sa and Molyneux, 1966; Roy, 1971).

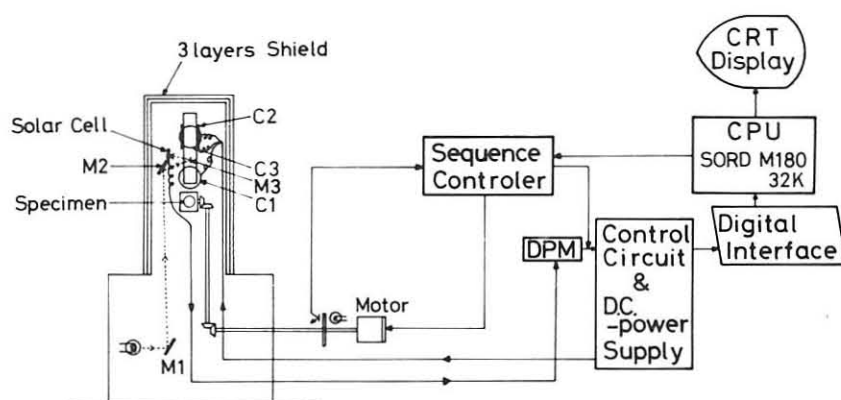
We make a design of an automatic computer controlled astatic magnetometer system which has multi-range sensitivity for various type of rocks and construct the instrument at the paleomagnetic laboratory of the Department of Geology and Mineralogy, Hokkaido University.

These are 3 basic principles for attempting to make this automatic system;

- 1) In order to avoid external magnetic noise from various sources, the magnet system and the specimen are located inside a multi-layered magnetic shield case.
- 2) The system has a broad band of sensitivity settings ranging from 10^{-2} to 10^{-7} emu/cc.
- 3) Rock specimen can be loaded automatically and the instrument can be left unattended in order to be free from personal errors.

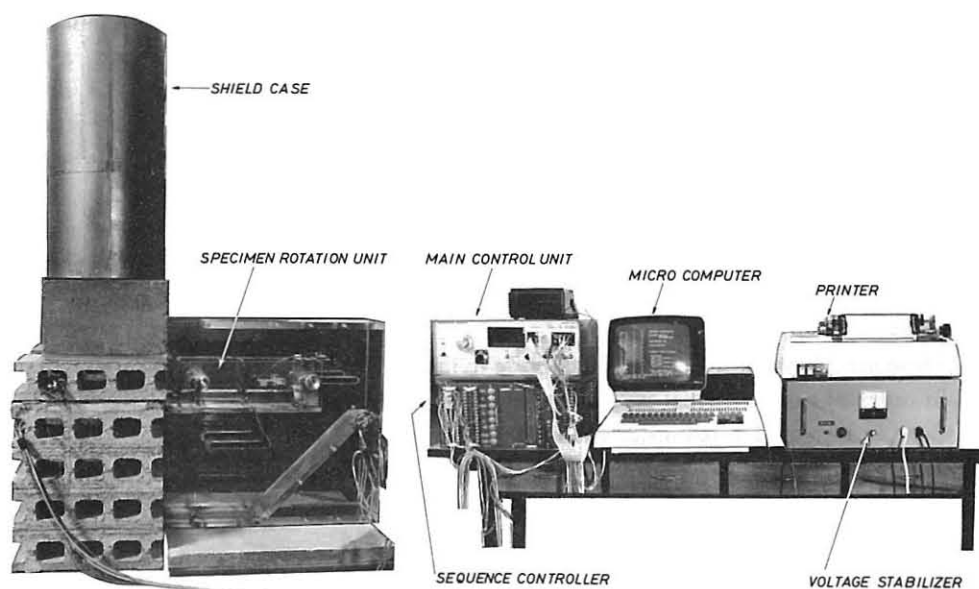
General lay-out

A schematic representation of this system is given in Text-Fig. 1 and Text-Fig. 2 gives a general view of the present system. Text-Fig. 3 represents a close up view of the present



Text-fig. 1. Schematic diagram of the automatic astatic magnetometer system.

astatic system and of the specimen holder unit which locate inside the magnetic shield case. This automatic magnetometer system consists of following five units; the astatic magnetometer, the specimen orientation unit, the sequence controller, the main control unit and the computer with CRT terminal and printer.

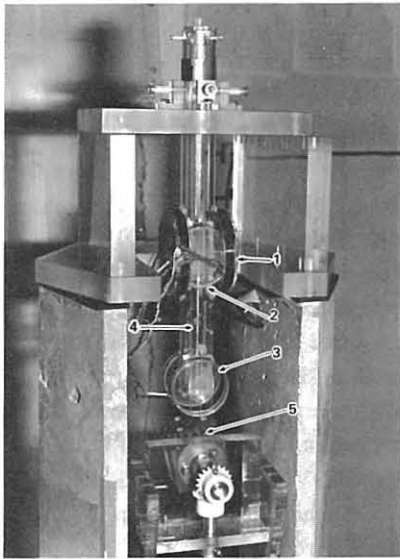


Text-fig. 2. General view of the automatic astatic magnetometer system.

Magnet system and specimen orientation unit

The magnet system is suspended by $10\ \mu$ nylon fiber and locates inside the plastic tube attached to the center of the magnetometer case. Two small samarium-cobalt magnets (3 mm $\times$ 4 mm) are supported by teflon holders 10 cm apart in anti-parallel form. A copper damping plate is adjusted closely underneath the magnet system for critical damping.

The specimen holder rotates the specimen about both vertical and horizontal positions much in the same way as the system of the Geological Survey of Canada described by Larochelle and Christie (1967). The holder is located co-axially with magnet system at a fixed distance. The motor rotates the specimen holder every 90° through aluminum shaft with two pairs of bevel gears which have a ratio of 1 : 1. The exact orientation of the specimen in each position is made by means of a disk with 4 slots attached to the shaft. Each slot allows a beam of light from the lamp house to reach the photocell once in each $1/4$ revolution of the shaft. These operations are triggered by command from the sequence controller.



Text-fig. 3. Close up view of the astatic magnetometer and the specimen holder unit. 1, 2, 3: Helmholtz coil. 4: magnet system. 5: specimen holder.

Multi-sensitivity system

As the specimen holder is placed below the magnet system as a fixed distance, this instrument has 7 different sensitivity ranges in order to make measurements of rocks which widely differ in their intensities of magnetization. For this purpose, two small Helmholtz coils (C1, C2 in Text-Fig.1) co-axially with each magnet are mounted on the magnetometer case. A voltage divider in the main control unit (see Text-Fig.2) controls the effective values of C1 and C2 current. Because of increasing of the torsion constant of the suspended system toward to higher sensitivity setting, the specimen holder is stand still for a given moment in proportion to the selected sensitivity range following sequential program stored into the

core memories of the sequence controller. The interval between re-orientation and data reading command (5 sec.—1 min.) is also automatically adjusted for each sensitivity setting. The sequence controller is achieved by coded signal the main control unit.

Table 1 Helmholtz coil current (mA), maximum sensitivity and coil constant

Range	C2-a (min. — max.)	C2-b	C1	Sensitivity (oe/digit)	Timer*
1		not to be commonly used			
2	—	4–15	+93	2.7×10^{-4}	5sec (T2)
3	—	0.5–1	+7.9	2.1×10^{-5}	5sec (T3)
4	1.6 –0.9	—	+0.92	4.3×10^{-6}	10sec (T4)
5	0.72–0.52	—	±0	1.4×10^{-6}	35sec (T5)
6	0.49–0.44	—	–0.21	3.2×10^{-7}	60sec (T6)
7	0.40–0.42	—	–0.25	8.0×10^{-8}	60sec (T6)

coil
constant 0.24 i/oe 5.20 i/oe 6.66 i/oe

*see Text-fig.4

Data processing

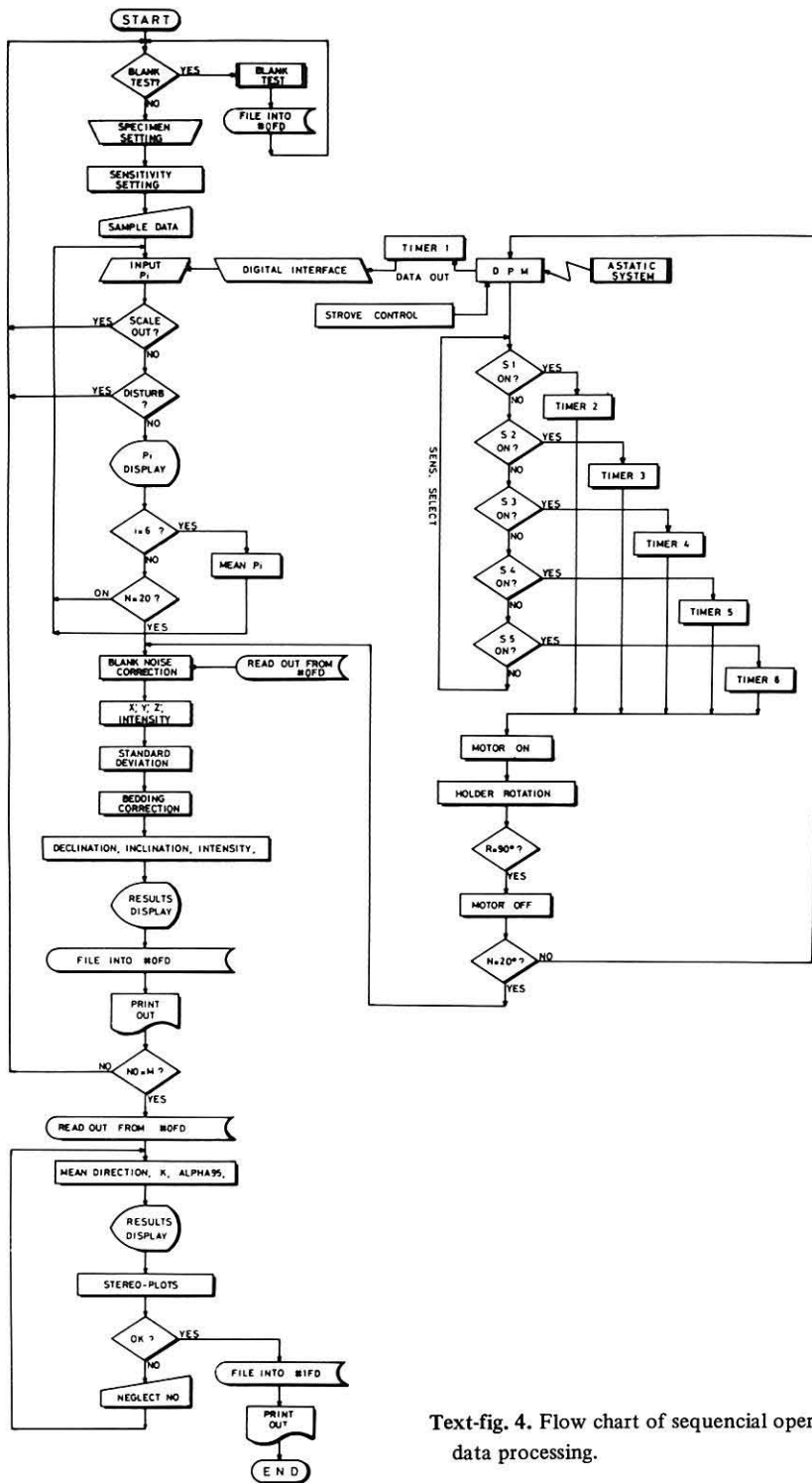
The angular deflections of the magnet system are determined optically. A light beam guided by two mirrors (M1, M2 in Text-Fig.1) from the lamp house is reflected from the mirror attached to the magnet system (M3), onto the wedge shaped solar cell. The analog output of the solar cell is converted into digital form in the analog – digital (A/D) converter (DPM in Text-Fig.1 and 4). The output of binary coded decimal (BCD) signal from A/D converter is introduced into the computer through 20 wired flat cable. The computer also receives pulses for data reading intervals from the main control unit. From these inputs the computer calculates and stores magnetic vector data for each position of specimen.

The signal readings, triggered by the main control unit are repeated 20 times after which the specimen is re-oriented in order to obtain reliable orthogonal components of remanent magnetization.

The following calculation programs written by BASIC Level IV programming language are executed by the computer (48 Kbite main memory, 150 Kbite floppy disk × 2);

- 1) Intensities of three orthogonal components (X' , Y' , Z').
- 2) Intensities of three orthogonal components after correction by the specimen geographic co-ordinates.
- 3) Total intensity of magnetization of the specimen.
- 4) Declination and inclination of the specimen.
- 5) Mean direction of magnetizations and statistic parameters.
- 6) Standard deviations of the intensities of three components on the basis of three groups of reading.

Usually these results are displayed on the CRT terminal and filed into the floppy disk and/or printed out on the serial dot printer if the operator gives a key board command for printing out.



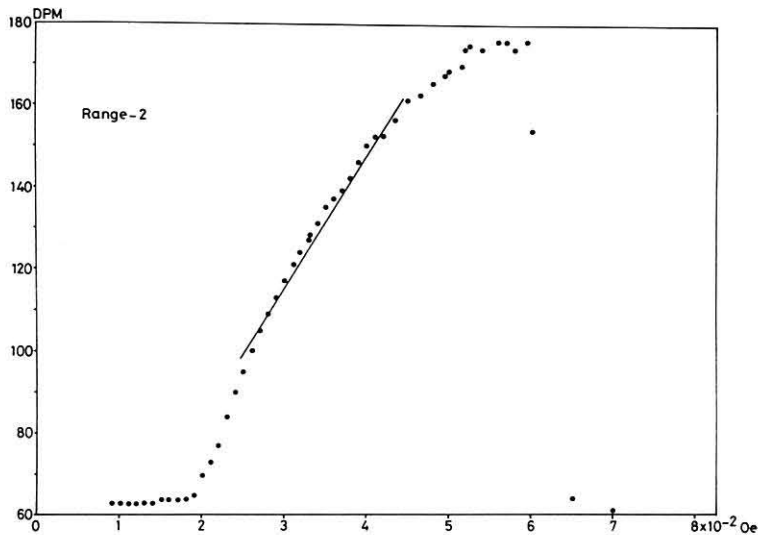
Text-fig. 4. Flow chart of sequential operations and data processing.

Operation and calibration

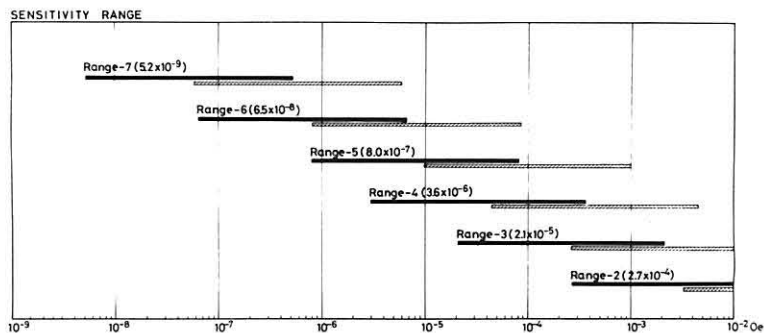
As described in the former chapter, the magnetometer operation is programmed in the core memories of the sequence controller from which commands are emitted to the A/D converter and specimen rotation mechanism. The basic sequence of operation is as follows;

- 1) Stand still the specimen holder for given seconds corresponding to the selected sensitivity setting.
- 2) Reading of the voltage corresponding to the angular deflection of the magnetic system.
- 3) Re-orientation of the specimen holder to the next position.

After which these operation are repeated 20 times, the results of calculations based on 20 reading data are displayed on the CRT terminal. Detailed sequential flow chart is illustrated in Text-Fig.4.

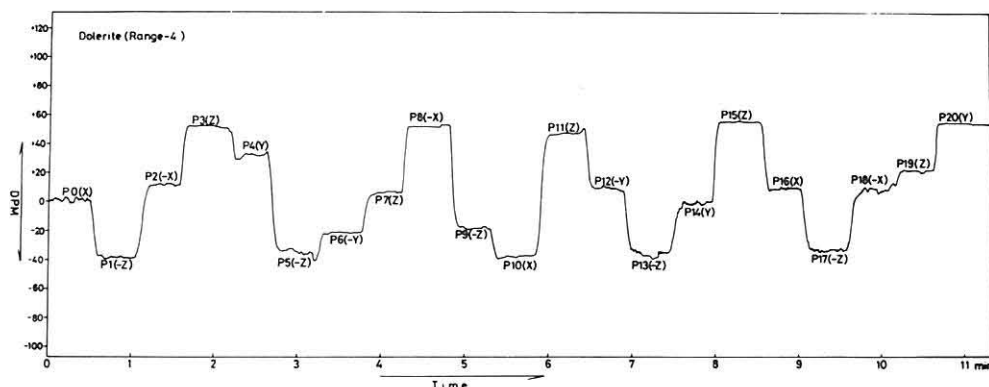


Text-fig. 5. Variation of reading signals for different values of magnetic field of the Helmholtz coil (C2).



Text-fig. 6. Ranges of measurable intensities at different sensitivity settings.

The variations of reading signals for different values of compensating magnetic fields, produced by the Helmholtz coil C2, are thoroughly calibrated for each sensitivity setting. The result of calibration at sensitivity range 2, for example, is represented in Text-Fig.5 Text-Fig.6 represents the ranges of measurable intensities at different sensitivity settings. Solid lines indicate ranges of sensitivity at the center of the Helmholtz coil (C2) and shaded lines indicate ranges of intensities measurable at the corresponding sensitivity settings. An example of the variation of reading signals for corresponding positions for the specimen of Cretaceous dolerite is given in Text-Fig.7. The measurement is made at sensitivity range 4.



Text-fig. 7 Variation of reading signals for corresponding positions. specimen: Upper Cretaceous dolerite, Nemuro Peninsula, Hokkaido.

The calculation program includes a provision for correcting measured data for any small remanent magnetization of the specimen holder. Very weak magnetization of the specimen holder can introduce a systematic error in work with very weak specimens. A blank measurement is made before setting the specimen to use this provision. Measurement data of the specimen holder is deposited in the computer memories as the specimen holder magnetization. The data for subsequent measurements will be automatically corrected by subtraction of the specimen holder magnetization.

The time required to obtain the directions and intensities of a specimen magnetized to an intensity of 10^{-7} order is about 25 min. and to intensity of 10^{-3} order is about 5 min.

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