Translated to English from paper in Japanese, originally published in: Gijutsu Houkoku, Vol.39, No.2 (No.109), 20-26, 2000 with permission of the authors.

New Observation Method Using a Fluxgate Theodolite Magnetometer

by

Takeshi OWADA[1], Fumio FUKUI[1], Megumi YOKOYAMA[1], Yasuhiro MINAMOTO[1], Yuki IWASE[1] and Takashi OKAWA[1]

[1]Kakioka Magnetic Observatory, Japan Meteorological Agency, Japan

1. Introduction

Geomagnetic absolute observation with a fluxgate theodolite (FT) magnetometer at a low geomagnetic latitude site with a shallow magnetic inclination requires the use of a prism in order to read the scale due to the structure of the magnetometer. In areas around the equator with even shallower inclinations, it would be impossible to read the scale even with a prism. In such a situation, there is no other choice but to employ extraordinary methods of observation (Owada, 1998).

The use of a prism for geomagnetic observation requires rotating the prism every time the magnetometer is turned around. Thereby, it will force complicated observation procedures, and induce putting the scale reader out of focus. That causes errors in scale reading as a result of refocusing the scale reader.

Even when the use of a prism is not required, geomagnetic observation often makes it necessary to read the scale in an unnatural position, thereby causing parallax errors.

In order to resolve these problems, we developed a new method of observation. The new method uses an offset control function of a fluxgate magnetometer (FM) mounted in an FT magnetometer. Adequate offset to subtract from the natural geomagnetic field could make easier to conduct observation in the direction in which the output of the FM becomes zero. In this article, we report on the results of observation conducted by using this method.

2. Method of observation

The FM mounted in the FT magnetometer used for observation in our research was a single-axis solenoid sensor manufactured either by Bartington Instruments or by Shimadzu Corporation. Of these sensors, the MAG-01H manufactured by Bartington Instruments has an offset control for up to ±90000 nT in 10000 nT steps. This FM makes it possible to continuously observe changes in one of the three geomagnetic components. Although absolute observation is normally conducted with the intensity of the offset to zero, we applied offsets with intensities of −10000 nT, −20000 nT and −40000 nT and calculated instrumental errors in measurements in comparison with the DI-72, the standard angle measuring instrument of Kakioka Magnetic Observatory, and compared these instrumental errors with errors obtained without any offset. Observation procedures are following:

a) Level measurement of the magnetometer
b) Observation of an azimuth mark
c) Observation of a declination
d) Observation of an azimuth mark
e) Observation of an inclination without offset
f) Observation of an inclination with offset to subtract from geomagnetic field

This sequence of the observation of an inclination and declination was repeated 10 times (to obtain four absolute observation values). The FT magnetometer used in our research is owned by the Technology Division (theodolite: Nr. 151571, FM: S.N. 0624H).

2-1. Results of the observation with offsets

Figures 1a through 1c and Table 1 show the results of normal observation and observation conducted by applying an offset. The result of normal observation shown in Table 1 is the average of three measurements taken before applying magnetic fields with an intensity of −10000 nT, −20000 nT and −40000 nT. The horizontal axes of figures 1a through 1c show observers and encircled letters indicate the same observer.

Figure 1a shows instrumental errors measured in normal observation and in observation conducted by applying a −10000 nT offset. The mean and standard deviation of instrumental errors in normal observation were 4.4″±1.9″ and the mean and standard deviation of ranges 2.1″±1.1″. The term “range” refers to the difference between the maximum and minimum of the four absolute observation values obtained from one sequence of observation. The range provides a measure for judging the accuracy of observation. The mean and standard deviation of instrumental errors in observation with offset were 2.4″±1.7″ and the mean and standard deviation of ranges 2.0″±1.6″. Instrumental errors decreased by about 2″ when the offset was applied, while there was no difference in range between the two sequences of observation.

Figure 1b shows instrumental errors in observation conducted by applying a −20000 nT offset. The mean of instrumental errors in normal observation was 4.3″ (±1.6″) and the mean of ranges 1.8″ (±0.5″). Meanwhile, the mean of instrumental errors in observation conducted by applying the offset was 2.6″ (±1.7″) and the mean of ranges 3.1″ (±1.7″). Although instrumental errors also decreased in this case by about 2″ when an offset was applied, ranges showed a slight increase.

Figure 1c shows instrumental errors in observation conducted by applying a 40000 nT offset. The mean of instrumental errors in normal observation was 5.3″ (±1.2″) and the mean of ranges 1.5″ (±0.8″). Meanwhile, the mean of instrumental errors in observation conducted with offset was 3.2″ (±2.3″) and the mean of ranges 5.0″ (±1.4″). Instrumental errors also decreased in this case by about 2″ when an offset was applied, showing the same tendency as in other cases with offset. However, ranges showed a considerable increase. In fact, when the −40000 nT magnetic field was applied, the output values of the FM showed a considerable variation, which

Table 1 Comparison with the Normal Observation Method

	Instrumental error	Range	Time required for observation
Normal observation	4.7 " ±1.59"	1.80"	14 minutes
-10000 nT applied	2.4 ±1.74	1.99"	15 minutes
-20000 nT applied	2.6 ±1.68	3.07"	16 minutes
-40000 nT applied	3.2 ±1.26	4.96"	17 minutes

Note: The result for normal observation is the average of three observations conducted before the application of -10000 nT,-20000 nT and -40000 nT.

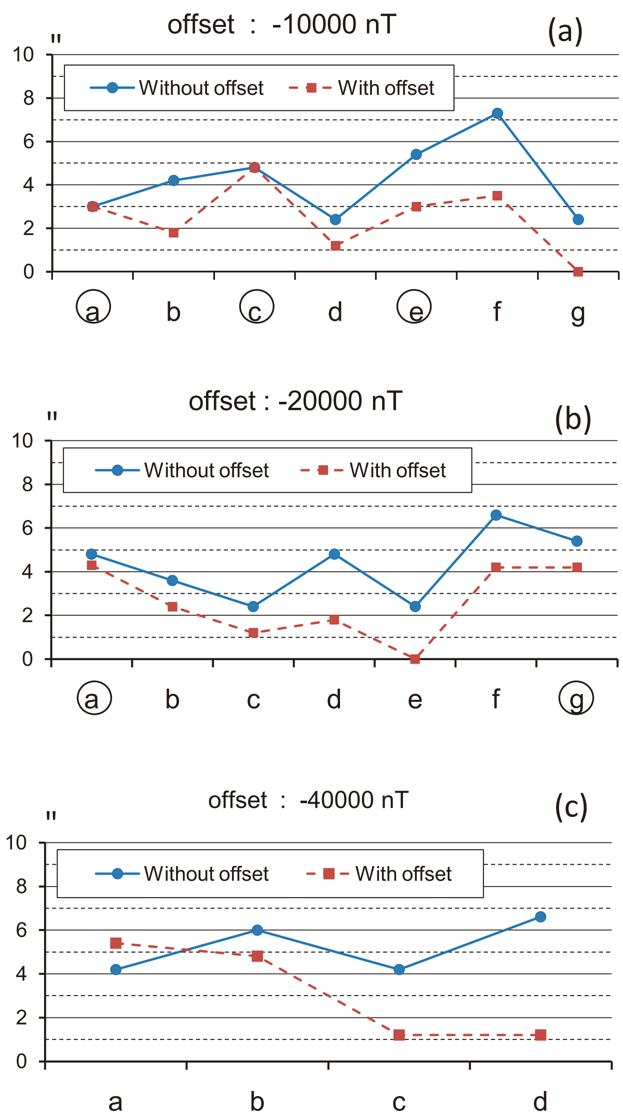


Fig. 1 Instrumental Errors in the Observation of Inclinations

we felt made observation difficult. This variation is likely to have been due to a decrease in voltage caused by a lack of capacity in the built-in battery of the FM, which in turn resulted from the need for a large amount of electricity to keep offsets.

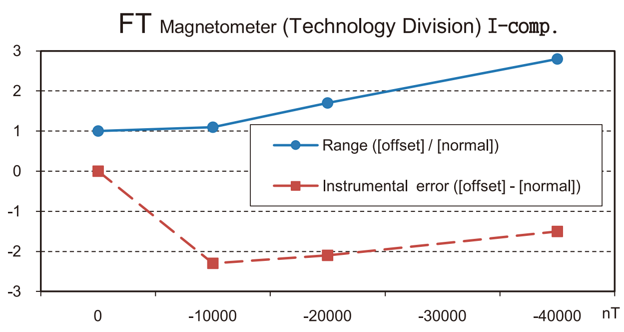
Figure 2 shows the relationship between the intensities of offsets and the changes in instrumental errors and ranges. Instrumental error and range in this graph are defined as difference between obtained data taken with offset and without offset, and ratio of obtained data with offset to without offset respectively. The graph shows that although instrumental errors are not significantly affected by the intensities of offsets, ranges depend on the intensities of magnetic fields, reaching a size about three times the size of ranges in normal observation when a −40000 nT magnetic field is applied.

2-2. Causes of changes in the instrumental error that occur when an offset is applied

Possible causes of changes in the instrumental error of a FT magnetometer are:

a) Position where the FM sensor is mounted (distance between the center of the sensor core and the center of the theodolite)
b) Errors in the mounting of the FM sensor (yaw and pitch)

However, yaw and pitch should be canceled by the vertical and horizontal turning around of the FM sensor in the observation respectively. Accordingly, errors mentioned in b) above cannot be the cause of the instrumental errors observed in our research. We therefore studied the cause in a).



The horizontal axis represents the intensities of the magnetic field (nT). The vertical axis represents instrumental errors (measured in seconds) and ranges (measured in ratio).

Fig. 2 Intensity of the offset and Changes in Instrumental Error and Range

Errors in the position where the FM sensor is mounted, mentioned in a) above, are corrected by rotating the FM sensor by 180 degrees and placing it in a symmetric position and therefore cause no problems in normal observation. However, in observation conducted with offset, errors in the absolute position of the FM sensor are not corrected when the output cable of the FM sensor is always placed in a direction opposite to the direction of the inclination during the observation, which is conducted in four directions. If the FM sensor is mounted in a position too far forward or backward in the telescope of the theodolite, an instrumental error occurs as a result of the difference in inclination between different observation points. The size of the error becomes larger at locations with larger magnetic field gradients.

2-3. Errors caused by changes of offset values

The reason why ranges show an increase depending on the intensity of the offset is that some errors are included in observed values. Changes in the offset during observation time (14 to 20 minutes) are a possible cause of errors that occur when the offset is applied. Assuming a change of 1 nT in the offset during observation time, the errors that would be caused by the change, as observed at the Kakioka Magnetic Observatory and on Chichijima Island and Christmas Islands, are presented in Table 2. The sizes of these errors vary depending on the intensity of the offset applied and the total magnetic intensity of the observation point. Although there is a need to test the stability of offsets generated by the FM, we did not conduct the test in our research. However, the sizes of the ranges of measurements in observation conducted with −10000 nT and −20000 nT offsets seem to suggest that there were no significant changes in the offset during our observation.

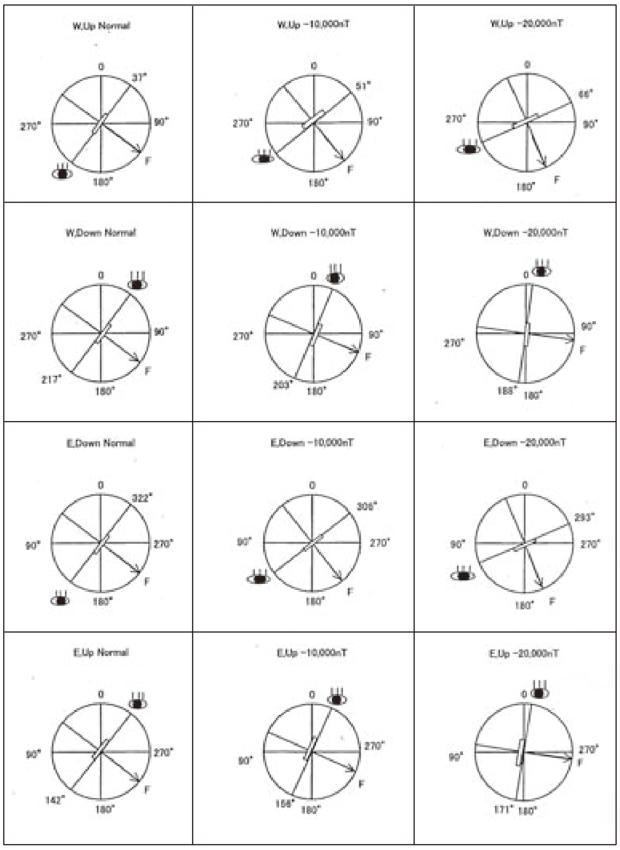
Table 2 Errors Caused by a Change of 1 nT in the offset

	Kakioka (F = 46000 nT)	Chichijima Island (F = 41000 nT)	Christmas Island (F = 33000 nT)
-10000 nT	4.6 "/nT	5.2 "/nT	6.6 "/nT
-20000 nT	5.0	5.8	7.9
-30000 nT	5.9	7.4	15.0
-40000 nT	9.1	22.9	—

3. Observation conducted on Chichijima Island with offset

Chichijima Island is the observation point with the shallowest inclination (about 37°) where absolute observation is regularly conducted by the Kakioka Magnetic Observatory. Observation on this island is conducted by using prisms, as would be expected.

Conceptual diagrams showing the scale reading positions in the observation of inclinations conducted on Chichijima Island by applying offsets are presented in Figure 3. Angles were calculated by assuming an inclination of 37° and a total magnetic intensity of 41000 nT. The application of a −10000 nT magnetic field creates a difference of about 13° in comparison with the scale used in normal observation and makes it possible to conduct observation without the use of a prism. The application of a −40000 nT magnetic field would make it possible to conduct observation at inclinations of about ±13° regardless of the position of the magnetometer. However, due to the difficulties mentioned in 2-3 regarding the stability of offsets during observation and the power consumption required for applying large offsets with the FM, it does not seem possible to apply offsets with intensity greater than −20000 nT on Chichijima Island, where no commercial power sources are available at the site.



"E" and "W" indicate the position of the vertical scale reader board and "Up" and "Down" indicate the position of the FM sensor.

Fig. 3 Conceptual Diagrams Showing the Scale Reading Positions in the Observation of Inclinations Conducted on Chichijima Island by Applying offset

4. Summary

In our recent research, we studied a new method of observation designed to use offset control of FMs mounted in FT magnetometers in order to conduct absolute observation without difficulty at a low geomagnetic latitude site with a shallow inclination. Observation conducted by using this new method of observation revealed the following findings:

a) The application of an offset creates changes in the size of instrumental errors. The instrumental error of the magnetometer used in our research decreased by about 2″.
b) An increase in the magnitude of the offset results in an increase in the range of observed values.
c) The new method can be used for observation on Chichijima Island as well. However, the maximum intensity of the offset that can be applied on Chichijima Island is −20000 nT.

Observation also revealed the following problems:

a) The new method, like the normal observation method, requires that observation be conducted by directing the FM sensor in four different directions. However, since angles observed differ greatly between the four directions, special caution is required when reading the angles in the first four observations.
b) Errors in the position where the FM sensor is mounted cannot be corrected and cause instrumental errors. These errors cannot be ignored at observation points with large magnetic field gradients.
c) The application of an offset increases the

power consumption required for the FM and decreases the amount of time for observation.

Based on these conclusions, we would like to employ this method for geomagnetic observation on Chichijima Island and for programs such as the Ocean Hemisphere Network Project led by the Earthquake Research Institute of the University of Tokyo in order to improve observation accuracy.

References

Takeshi Owada, Geomagnetic Absolute Observation in Areas Around the Equator, *Gijutsu Houkoku of the Kakioka Magnetic Observatory*, 106, 131–141, 1998 (in Japanese).

Kakioka Magnetic Observatory, Observation Guidelines, *Gijutsu Houkoku of the Kakioka Magnetic Observatory*, 34, Special Issue, 85–122, 1994 (in Japanese).