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Stability of Vector Proton Magnetometer at Memambetsu Magnetic Observatory

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Abstract

Absolute values of H-, Z-, and F-components have been measured by a vector proton magnetometer with a high reliability at Memambetsu Magnetic Observatory, in Japan. The purpose of the present paper is to introduce the experimental results of the absolute observation with the vector proton magnetometer in comparison with those by the convenient absolute observation using the magnetic theodolite and the proton magnetometer.

1. Introduction

Magnetic observation consists of the absolute observation and the variation observation. A definition of the absolute observation is to measure the magnetic elements (H, Z, D, or X, Y, Z, for example) with an accuracy at least of the order of resolution of the recording instruments. In conventional way, the absolute observation has been carried out using the proton magnetometer for the measurement of the total force (F) and the magnetic theodolite for the measurement of both the declination (D) and the inclination (I) of the direction of the magnetic field line at the observing point. Because very high-level technique is required for the treatment of the magnetic theodolite, the automatically observation is very difficult in the convenient absolute observation.

Several researchers have tried to use a vector proton magnetometer to measure not only the total force intensity (F) of the magnetic field, but also its direction, namely declination (D) and inclination (I) (Hurwitz and Nelson, 1960; Sakuraoka, 1966; Sano, 1971; and others). Semi-automatic absolute observation already has been carried out by observing F and H by using the vector proton magnetometer (Sugawara and Kuwashima, 1981; Hasegawa, 1982; Hasegawa et al., 1983; Hasegawa and Sugawara, 1984; Sugawara, 1985). Their results show very stable automatical absolute observation by the vector proton magnetometer. However, their vector proton magnetometer measure only the H-component, and the Z-component is calculated by the following way,

$$Z=\sqrt{F\cdot F-H\cdot H}$$

The previous results show that unstability of the observation by the vector proton magnetometer is caused by the following conditions,

(1) Unstability of the helmholz coil current which produce the bias field for the measurement of the specified component.

(2) Inclination of the helmholz coil depending on the ambient temperature, etc.

(3) Discrepancy between the mechanical axis and the electrical one of the helmholz coil system.

In the present paper, the stability of the absolute observation by the vector proton magnetometer will be discussed considering the conditions above mentioned.

2. Outline of the instruments

A vector proton magnetometer for the absolute magnetic observation has been installed at Memambetsu Magnetic Observatory, which is one of the branch observatory of Kakioka Magnetic Observatory, in 1975. It is abbreviated as MOP-75, because magnetometer was installed at Memambetsu in 1975. MOP-75 consists of a proton-precession magnetometer and two helmholz coil systems which create bias field for the observation of the specified components (H and Z). MOP-75 has been designed to measure the geomagnetic field F, H and Z with an accuracy of 0.2nT. The expected ability has been confirmed to be satisfied by the experimental results discussed in the later sections.

A stability of the vector proton magnetometer depends upon both the stability of the bias field produced by the bias helmholz coils and the stability of the signal from the proton magnetometer. The stability of the signal from the proton magnetometer is increased with increasing the size of the senser. While, a ratio of the size of the senser of the proton magnetometer to that of the helmholz coil must be kept less than 1/10 to keep the uniform bias field to the senser. Considering those conditions, the size of the helmholz coil and the size of the senser of the proton magnetometer have been determined as summarized in Table 1. For the senser of the proton magnetometer, two

Table 1. Factors of the Helmholtz coil

		Diameter mm	Length mm	Turn	Coil constant nT/mA	DC resistance ohm
Helmholtz coil	H	500		396	1424.0	112.97
	Z	600		480	1438.4	164.03
Sensor	CF	50	50	1176		
	TF	80	100	1122		

kinds of senser are employed. The one is for the measurement of the specified component of the geomagnetic field and is abbreviated as CF. The other is for the measurement of the total field and is abbreviated as TF. Fig. 1 shows an outline of the instruments of the vector proton magnetometer.

Usually, absolute magnetic observation is carried out by the magnetic theodolite (abbreviated as DI-75) and the proton magnetometer (TF of MOP-75) at Memambetsu Magnetic Observatory. Because adjustment of the theodolite is carried out by the observer by handling, it is impossible to measure the geomagnetic field automatically in the convenient observation using the magnetic theodolite. On the other hand, automatic measurement is possible at every 10 second or every 1 minute for MOP-75. Fig. 2 shows an outlook of the senser part of MOP-75. The senser (CF) is set at the center part of the two helmholz coil systems. Both CF and the Helmholz coil systems can be rotated in the horizontal plane freely. The direction of the senser or the helmholz coil can be monitoring by reading the attached microscopes.

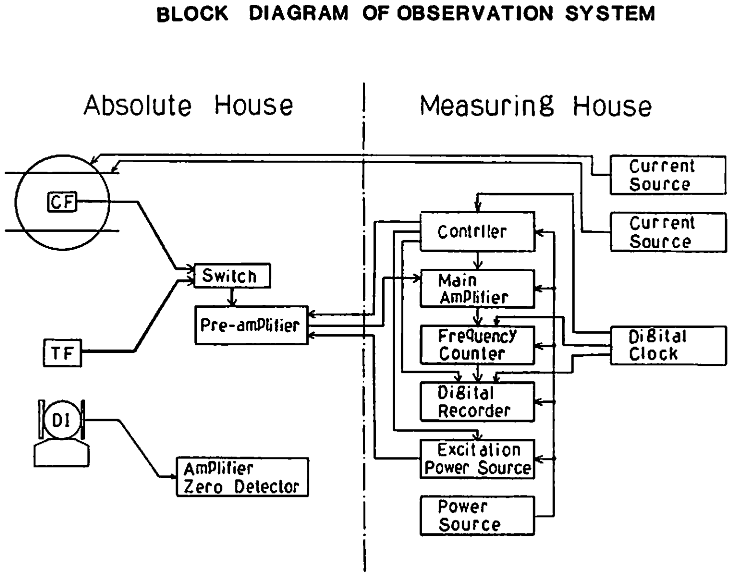

Fig. 1. Block diagram of the vector proton magnetometer installed at the Memambetsu observatory. The magnetometer is abbreviated to MOP-75. CF is the senser of the proton magnetometer for the observation of the special component, while TF is the one for the observation of the total force. DI is the magnetic theodolite for the observation of the declination (D) and inclination (I).

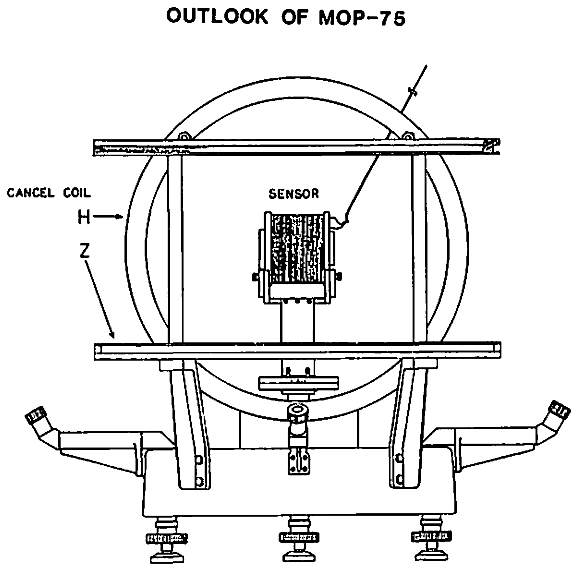

Fig. 2. Outlook of the senser part of MOP-75. That is consisted of the senser of the proton magnetometer (CF) and two helmholz coil systems to add the bias field to CF.

3. Outline of the observation

Principles of the observation with the vector proton magnetometer are illustrated in Figs. 3~5. In order to increase an accuracy of observation, the observation is carried out with a set in which the helmholz coil system is rotated 180° with each other. A set of observation is carried out several times by rotating the helmholz coil 180°. A adopted value is an average of these observations. The outline of the observation will be described hereafter.

At first, the direction of the magnetci meridian is searched to set the H-component helmholz coil along the meridian. The direction of the magnetic meridian is searched as follows. The helmholz coil is set approximately parallel to the magnetic meridian. Then, the bias field whose magnitude is approximately equal to the H-component, H', is added to obtain a composed component, D^+, as shown in Fig. 3. Then the direction of the current flowed in the helmholz coil is reversed to produce, $-H'$, to obtain D^-. The direction of the helmholz coil is adjusted to be satisfied a condition of $D^+ = D^-$ where the direction of the helmholz coil system is just parallel to the magnetic meridian. Such the adjustment also is carried out by rotating the helmholz coil of 180°. Therefore, the adjustment for searching the direction of the magnetic meridian is carried out with a case of 0° of the helmholz coil system and with that of 180° one. The mean value of the observation of 0° and 180° is adoppted as the direction of the magnetic meridian. We could determine the direction of the magnetic meridian in an accuracy of 2nT with the horizontal magnetic field intensity of about 26000nT.

Fig. 4 illustrates the method to determine the cancell current of the H-component. In the figure, the cancell current is adjusted to be $F = Fh$, in which the bias field is twice of the horizontal component with a reverse direction, $-2H'$, as sown in Fig. 4. Such the adjustment is carried out by rotating the helmholz coil 180° in the horizontal plane. Then, the H-component cancell current is determined as a half of the adjustment current, namely $H' = 2H'/2$. Estimation of the observation error by the bias field is examined by the relationship of dH' and dZ' as shown in Fig. 4. An error of 50nT in dH will cause an error of 0.03nT in dZ in a case of Z-component magnetic field intensity of 41500nT. We can easily make an observation keeping the error of dH within a few nT so that the observation error of the Z-component from the bias field to be negligible.

Fig. 5 illustrates the method to determine the cancell current of the Z-component. In the figure, the cancell current is adjusted to be $F = F_z$, in which the bias field is twice of the vertical component with a reverse direction, $-2Z'$, as shown in Fig. 5. Such the adjustment is carried out by rotating the helmholz coil 180° in the horizontal plane. Then, the Z-component cancell current is determined as a half of the adjustment current, namely $Z' = 2Z'/2$. Estimation of the observation error by the bias field is examined by the relationship of dZ' and dH' as shown in Fig. 5. An error of 40nT in dZ will cause an error of 0.03nT in dH in a case of H-component magnetic field intensity of 26500nT. We can easily make an observation keeping the error of dZ within a few nT so that the observation error of the H-component from the bias field to be negligible, in this case too.

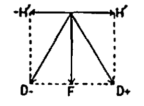

Fig. 3. Principle for the determina tion of the direction of the magnetic meridian. The magnetic field of H' and $-H'$ is produced alternatively with adjusting the direction of the helmholz coil in order to be $D^+ = D^-$, in which the helmholz coil system is directed along the magnetic meridian.

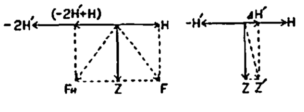

Fig. 4. Principle for the measure ment of the Z-component of the geomagnetic field by the vector proton magnetometer.

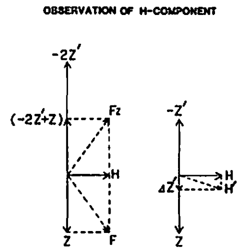

Fig. 5. Principle for the measurement of the H-component of the geomagnetic field by the vector proton magnetometer.

Table 2. Example of the observation

F	2	01	0350	49170.4nT
	1	01	0343	49170.7
	0	01	0335	49170.2
Fz	9	01	0302	49171.2
	8	01	0254	49170.6
	7	01	0247	49170.5
Current adj.	6	01	0239	49170.7
	5	01	0230	49174.1
	4	01	0271	49178.7
	3	01	0212	49166.3
	2	01	0204	49141.7
	1	01	0152	49130.4
F_H	0	01	0144	49169.6
	9	01	0134	49169.9
	8	01	0126	49169.5
	7	01	0118	49170.0
Current adj.	6	01	0109	49170.2
	5	01	0100	49154.3
	4	01	0046	49116.8
	3	01	0036	49192.7
F	2	01	0029	49170.6
	1	01	0021	49170.7
	0	01	0014	49169.9
D−	9	00	5854	55780.1
	8	00	5847	55780.2
	7	00	5839	55780.3
D+	6	00	5833	55780.5
	5	00	5825	55780.4
	4	00	5818	55780.5
Angle adj.	3	00	5811	55780.2
	2	00	5904	55780.1
	1	00	5727	55779.6
	0	00	5720	55781.1
	9	00	5711	55781.0
	8	00	5648	55782.9
	7	00	5640	55777.6

F(E)	6	01	1353	49170.4nT
	5	01	1345	49170.6
	4	01	133[illegible]	49170.6
H(E)	3	01	1330	26373.4
	2	01	1323	26374.1
	1	01	1316	26374.2
Z(E)	0	01	1308	41505.3
	9	01	1301	41505.6
	8	01	1253	41505.5
Z(W)	7	01	1219	41488.6
	6	01	1212	41488.4
	5	01	1204	41488.6
H(W)	4	01	1156	26379.9
	3	01	1149	26380.2
	2	01	1142	26380.3
F(W)	1	01	1133	49169.9
	0	01	1126	49170.8
	9	01	1119	49170.6
H(W)	8	01	1111	26380.3
	7	01	1104	26380.7
	6	01	1057	26380.3
Z(W)	5	01	1049	41488.7
	4	01	1042	41488.9
	3	01	1034	41488.9
Z(E)	2	01	1001	41505.9
	1	01	0954	41505.8
	0	01	0947	41505.5
H(E)	9	01	0937	26374.8
	8	01	0930	26374.3
	7	01	0922	26374.5
F(E)	6	01	0914	49171.1
	5	01	0906	49171.1
	4	01	0859	49171.0

Table 2 shows an example of the observation by MOP-75. Left-hand side of the table shows the records of the adjustment of the cancel current for the Z-component (F_z) and that for the H-component (Fh), and for the adjustment of the direction of the magnetic meridian (D^+ and D^-). Right hand side of the table shows records for the observation of the F-, H-, and Z-components. The marks of (E) and (W) represent the observation rotating the helmholz coil of 180° with each other. There are differences of 6nT and 17nT between the observation of (E) and (W) with the H- and Z-components, respectively. These differences will be caused by a discrepancy between the mechanical axis and the electrical one of the helmholz coil system. These differences can be cancelled by averaging the two kinds of data of (E) and (W).

4. Results of the Observation

The experimental results for the period from January to December, 1985, will be discussed. At first, F-component obtained by the direct measurement of the total force is compared with that obtained from H- and Z-components by the relationship of

$$F' = \sqrt{H \cdot H + Z \cdot Z.}$$

The standard deviation of $(F - F')$ is $+0.24$nT. The comparison also is carried out between F from the direct observation and F″ obtained from the direct observation of another proton magnetometer. The standard deviation of $(F - F'')$ is $+0.31$nT. Therefore, we could not find any clearly effect from the bias field. The experimental results suggest that the effect depending on the bias field is negligible small.

Fig. 6 shows standard deviations of the base line values of the H- and Z-components with both the MOP-75 and DI-75. These base line values are obtained for the fluxgate magnetometer. It is clearly seen in Fig. 6 that the observation by MOP-75 is more stable than that by the conventional method by the magnetic theodolite (DI-75). With the absolute observation by MOP-75, the standard deviations are kept less than 0.2nT for both the H- and Z-components. With the observation by the theodolite (DI-75), the standard deviations are larger than that of MOP-75 suggesting more unstable observation because of unstabilities caused by the observer in adjustment of the theodolite and reading of the direction.

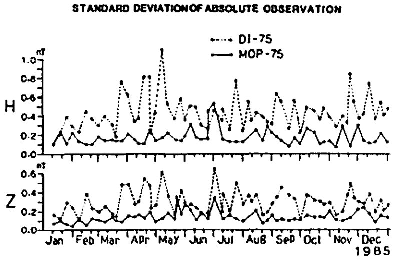

Fig 6. Standard deviation for the base line values of the fluxgate magnetometer from the observation by MOP-75 (vector proton magnetometer) and DI-75 (magnetic theodolite).

Fig. 7 shows temperature effects of the base line values for both MOP-75 and DI-75. A main cause of the temperature effect of the base line values is attributed to the temperature dependent drift motion of the fluxgate magnetometer. The slope shown in Fig. 7 is attributed mainly to the temperature effect of the senser part of the fluxgate magnetometer. On the slope in the figure, small fluctuations are overlapped. Those fluctuations are results of the error at the absolute observation. As shown in Fig. 7, the slope is more smooth in the observation by MOP-75 than that by DI-75 indicating more stable observation in MOP-75.

The experimental results for the observation of MOP-75 and DI-75 are summarized in Fig. 8. The figure shows room temperature, inclination of bed where senser is set, daily and observed base line values of the H- and Z-components for both the MOP-75 and DI-75, and the differences between the daily base line value and the observed one. The daily and observed base line value are defined as follows,

$$B_o = B_{obs} - \alpha(T_s - 20) - L$$
$$B_{daily} = B_o + \alpha(T_s + 20) + L$$

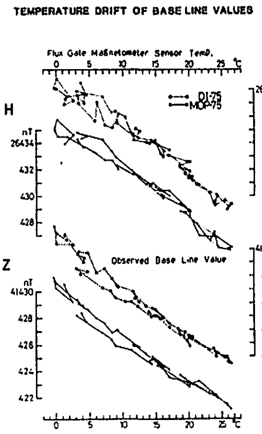

Fig. 7. Temperature dependence of the base line values of the fluxgate magnetometer from the observation by MOP-75 (vector proton magnetometer) and by DI-75 (magnetic theodolite).

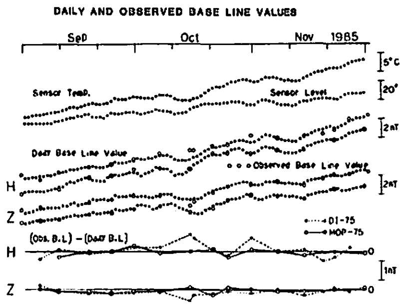

Fig. 8. Temperature of the fluxgate senser room, inclination of the pillar where the fluxgate senser is laid, daily and observed base line values of the fluxgate magnetometer obtained from the absolute observation by MOP-75 and DI-75, difference between the daily base line values and the observed ones. The difference is smaller in MOP-75 observation indicating more stable observation than that of DI-75.

where

B_{obs} : Observational base line value
B_0 : Monthly mean base line value
B_{daily} : Daily mean base line value
α : Temperature coefficient
T_s : Temperature of the senser room
L : Level of the bed where senser is set

The scattering of the difference between the daily base line values and that of the observed ones is less in the observations of MOP-75 than that of DI-75 indicating more stable absolute observation by MOP-75.

5. Conclusion

The absolute observation by the vector proton magnetometer has been examined with the experimental results comparing with that by the conventional absolute observation using the magnetic theodolite. It is suggested that the vector proton magnetometer could be employed as a new system for the absolute observation in the magnetic observatory.

60 absolute observations were carried out during January to December, 1985. The standard deviation of the observed values is very small within 0.2nT for both the H- and Z-components indicating a very stable absolute observation. That observational result supports that MOP-75 could measure the absolute magnetic field with an accuracy of 0.2nT.

The convenient absolute observation method using the magnetic theodolite contains undesirable contaminations, which are caused by the uncertainties of the adjustment of the search coil of the theodolite, uncertainties of the reading the scale, etc. On the other hand, The measurement by the vector proton magnetometer does not include such the uncertainties. We can also measure the absolute observation automatically using the vector proton magnetometer.

The reserved problems for the vector proton magnetometer is a measurement for the declination (D). However, method for the observation of the declination (D) by using the vector proton magnetometer also has been developing (Lauridsen, 1984). Such the effort should be continued to establish an automatically observation system.

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女満別出張所に設置された
ベクトルプロトン磁力計の安定性

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概　要

地磁気観測所女満別出張所では，ベクトルプロトン磁力計による地磁気全磁力，水平分力，鉛直分力の絶対観測を高精度で実施している。本論文では，ベクトルプロトン磁力計による絶対観測精度を，従来行われてきた角度測定器とプロトン磁力計との組み合わせ方式による絶対観測の結果と対比しながら論ずる。