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Experiment of Observation for Declination and Inclination with a Fluxgate-magnetometer-mounted-Theodolite

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Abstract

A fluxgate-magnetometer-mounted-theodolite was experimented for observation of declination and inclination. By initial experience, a newly purchased sensor which is less influenced by the surrounding conductors was introduced. We repeated the measurement for five months with the instrument fixed on a pillar. As a result of comparison with the standard instrument of Kakioka observed on the same days, the difference between the two and the variation were small. Then, synchronous measurement with the two instruments on D-and I-reducible pillars showed good agreement. So, it is confirmed that this instrument has good performance equal to the standard instrument of Kakioka.

Introduction

A proton magnetometer and a magnetometer-theodolite (the detector is a rotating coil) are used for absolute observation in the Kakioka Magnetic Observatory. The magnetometer-theodolite was manufactured over 15 years ago. The manufacturer discontinued the production. It will be impossible to maintain it in the near future. Then, to replace this instrument, a new one with a fluxgate magnetometer supported in an altazimuth mounting was produced for experiment in 1984. But the experiment was not succesful by reason that the magnetometer was influenced by surrounding conductors. After that, we knew non-magnetic theodolites each with a fluxgate magnetometer had been operating succesfully in European and North American countries [Kring Lauridsen, 1985; Newitt et al., 1988; Gilbert et al., 1988] . So we started an experiment with a similar instrument. The present paper reports the experiment and the results.

Instrument

In 1988, a 1-second theodolite(Carl Zeiss JENA, THEO 010B steel-free) was introduced to Kakioka. The test by an astatic magnetometer showed the theodolite was nonmagnetic. At first, we used a fluxgate magnetometer (SCHONSTEDT MND-5C-25-NB) which we had been possessed of, as a detector. We had examined that this magnetometer was influenced less than 0.1nT by the surrounding conductors which were distant over 3cm from the sensor. But there was a little possibility that the magnetometer sensor might approach to the theodolite within 3cm while the declination (D)-or inclination (I)-measurement. We made a mounting of acrylic resin to attach the sensor to the telescope of the theodolite. This mounting has four alignment-adjustable screws. It is possible to adjust the direction of the sensor whithin 10 seconds of arc to the ideal direction. As the sensor can be shifted easily by the elastic heavy cable, the mounting should be made firmly. Furthermore, we changed the cable to a thinner and more flexible one; and bound the sensor-side of the cable to the mounting. And we assembled a power supply, a digital panel meter and a lighting unit for the micrometer of the theodolite; we took care so that they did not generate electromagnetic noise. We call this system made up of the above parts "FT88" (Fluxgate magnetometer mounted Theodolite, 1988).

We continued to improve and to adjust this system during 1988. Then the accuracy of observation of declination or inclination became better than 10 seconds of arc, in spite of the possibility of influence by the surrounding conductors.

From these experience, we purchased a new fluxgate magnetometer (SHIMADZU CORPORATION), in order to improve the accuracy. This is less influenced by surrounding conductors, and is lownoise, and have a light-weight flexible cable. This magnetometer is influenced less than 0.1nT by the surrounding conductors which are distant over 1cm from the sensor; and the noise level is about 0.3nTp-p. We use this magnetometer for the experiment since April, 1989.

Observation method

A zero method is used for the observation. When the sensor indicates zero, it is perpendicular to the magnetic field line. In the case of D-measurement, the sensor searches such a zero in four possible positions in a horizontal plane, that is, the sensor is up-or down-side of the telescope which points to east or west. D is calculated by the four azimuth readings and the sighting of an azimuth reference mark. The errors due to misalignment of the sensor and due to the offset of the sensor output are eliminated through the calculation process, if they can be assumed to be constant in four positions. In the case of I-measurement, the sensor is placed in a plane parallel to the magnetic meridian, and searches a zero in four possible positions similarly to the D-measurement process. I is calculated by the four readings of the zenith angle.

Comparison with the standard instrument

From June to November in 1989, we fixed the FT88 on a pillar and repeated the observation on the same days with those with the standard instrument of Kakioka (magnetometer-theodolite DI-72). Then the calibration values for the values with optical pumping magnetometer system of KASMMER (Kakioka Automatic Standard MagnetoMetER) were calculated from the observed D and I. One set of observation consists of such four values of D and of I mentioned in the former section. An example of the observation notes is shown in Figure 1, and that of the calculation sheets in Figure 2.

Table 1 and Figure 3 show the values with the two instruments, and the differences. The values with the DI-72 are adopted values as the absolute observation in Kakioka.There are 24 pairs of the observed values in the period. But only 20 pairs for D, and 22 pairs for I are available except the disturbed values by artificial noise and the incorrect values by the failure of observation. 11 staffs observed by turns, including several inexperienced.

The mean difference of the values with the two instruments for D is 5.5″ (standard deviation: s. d. 1.7″) ; that for I is 1.5″ (s. d. 2.0″). Considering that the measuring accuracy of the theodolite is 1″ and the resolution of the sensor is 0.1nT, these s.d. are reasonable. Systematic errors are not notable even by inexperienced observers. The differences of the values for D are rather large and systematic. A wrong estimation of the difference with the two instruments or on the two pillars may cause such differences. But

Table 1 Calibration values for the optical pumping magnetometer system in the period from July to November, 1989.

	D			I		
date	FT88	DI-72	DIFF.	FT88	DI-72	DIFF.
1989/	″	″	″	″	″	″
7/19	-13.3	-17.9	4.6	-5.4	-6.6	1.2
25	---	-17.2		-5.8	-6.7	0.9
31	-13.7	-17.0	3.3	-6.8	-5.9	-0.9
8/ 7	-15.4	-21.7	6.3	---	-9.9	
15	-12.1	-19.3	7.2	-5.7	-8.1	2.4
31	-13.9	-19.8	5.9	-5.4	-6.2	0.8
〃	-13.7	〃	6.1	-6.6	〃	-0.4
〃	-14.3	〃	5.5	-6.2	〃	0.0
9/ 7	-14.9	-23.5	8.6	---	-5.5	
〃	-16.0	〃	7.5	-3.4	〃	2.1
13	-13.0	-21.8	8.8	-3.8	-6.6	2.8
21	-17.1	-21.3	4.2	-4.2	-4.3	0.1
30	-14.9	-20.0	5.1	-5.1	-6.8	1.7
10/ 5	---	-18.8		-7.6	-6.5	-1.1
6	-14.6	-21.2	6.6	-6.9	-8.0	1.1
18	-18.2	-22.6	4.4	-4.2	-7.9	3.7
23	---	-19.1		-2.3	-7.2	4.9
31	-17.0	-21.2	4.2	-5.9	-6.8	0.9
11/ 7	---	-21.2		-1.9	-8.1	6.2
14	-16.5	-21.8	5.3	-2.4	-7.0	4.6
〃	-15.4	〃	6.4	-4.9	〃	2.1
〃	-16.4	〃	5.4	-5.6	〃	1.4
30	-14.1	-17.4	3.3	-6.6	-6.4	-0.2
〃	-15.3	〃	2.1	-7.9	〃	-1.5
n			20			22
mean			5.54			1.49
s.d.			1.74			2.01

Obs.Point 第2絶対観測室 北台 (cm) Date Nov. 14 1989 Observer 上井 Recorder 福島

Instrument FT88
Theodolite (Nr.150213 ,Nr.151571)
Sensor (SCHONSTEDT,SHIMADZU ,TIERRA TEC)
Mount (No.1 ,No.2 ,No.3 ,No.4 ,No.5 ,No.6)

Level (V.C. = 89°59'60")

obj. lens	time h m	read 1 90° + "	2	mean "
N	4 30.9	0.0	--	--
E	31.2	+12.6	+14.2	+13.4
S	31.5	+13.0	+12.0	+12.5
W	32.0	+0.1	-1.2	-0.55
N	32.5	+0.4	+0.2	+0.3

	"
(N-S)/2	-6.1
(E-W)/2	+6.975

Declination (assumed sensor offset 0.0 nT)

V.C.	sensor (V.C.)	⊥	time h m s	read 1 ° ' "	read 2 "	mean ° ' "	V.C. 1 90°(270°) + "	2	mean	→ ×1.15 ↓ ±) corr.	corrected ° ' "
N	UP (90°)	✓	4 43 14	340 33 59.1	59.1	59.1	+2.5	+2.6	+2.55	-) +2.93	340 33 56.17
S		✓	45 06	160 31 41.2	41.5	41.35	+1.8	+1.4	+1.6	+) +1.84	160 31 43.19
	DOWN (270°)	✓	46 50	160 30 33.6	33.7	33.65	+0.8	+0.7	+0.75	+) +0.86	160 30 34.51
N		✓	48 44	340 33 11.9	12.0	11.95	-0.5	-1.1	-0.8	-) -0.92	340 33 12.87
	UP (90°)	✓	50 42	340 33 54.9	55.0	54.95	+2.8	+3.0	+2.9	-) +3.34	340 33 51.61
S		✓	52 21	160 31 33.9	34.6	34.25	+1.2	+1.2	+1.2	+) +1.38	160 31 35.63
	DOWN (270°)	✓	54 28	160 30 23.8	24.2	24.0	-0.9	-1.0	-0.95	+) -1.09	160 30 22.91
N		✓	56 25	340 33 10.6	10.7	10.65	-0.2	-0.5	-0.35	-) -0.40	340 33 11.05
	UP (90°)	✓	58 37	340 33 49.9	49.8	49.85	+2.5	+1.5	+2.0	-) +2.30	340 33 47.55
S		✓	5 00 28	160 31 26.4	25.8	26.1	+0.7	+0.4	+0.55	+) +0.63	160 31 26.73

Inclination (assumed meridian 250 °30 ' ")

V.C. (H.C.)	∇	sensor	time h m s	read 1 ° ' "	read 2 "	mean ° ' "
W (250)	✓	UP	5 08 31	49 17 16.1	16.8	49 17 16.45
		DOWN	09 49	229 17 13.1	14.1	229 17 13.60
E (70)	✓	DOWN	11 32	310 40 39.7	36.0	310 40 37.85
		UP	13 06	130 40 38.6	38.9	130 40 38.75
W (250)	✓	UP	14 50	49 17 12.8	12.0	49 17 12.40
		DOWN	16 08	229 17 12.8	11.9	229 17 12.35
E (70)	✓	DOWN	18 02	310 40 29.8	28.1	310 40 28.95
		UP	19 42	130 40 33.9	33.9	130 40 33.90
W (250)	✓	UP	21 26	49 17 22.1	22.2	49 17 22.15
		DOWN	23 10	229 17 19.2	19.3	229 17 19.25

T.mark

	time h m	T. read 1 ° ' "	° ' 2 "
L	4 36.7	257 45 09.7	09.0
R	37.8	77 45 05.1	04.6
R	38.7	05.1	05.6
L	40.0	08.0	07.9

L	02.6	257 45 13.9	13.0
R	03.6	77 45 04.2	04.6
R	04.6	05.3	05.5
L	05.4	09.1	11.1

	mean	s.d. all	s.d. popl.
L	10.213	2.103	
R	5.000	0.458	
all	7.606	1.522	1.572
L-R	5.213		

	° ' "
T.mark	257 45 07.61

FT88観測表 ver. 5.3

Figure 1 Example of the observation notes.

date 1989 11 14 obs. Uwai rec. Fukushima assumed zero offset 0.0nT

Declination

	UT h	m	s	A °	'	"	Dop °	'	A± π/2-Dop °	'	"	→ average °	'	"	δ "	ε "	S0 nT
A 11	4	43	14	340	33	56.2	-6	52.84	257	26	46.6						
A 12		45	6	160	31	43.2	-6	52.88	257	24	36.0						
												257	25	14.6	-26.6	62.9	-1.04
A 13		46	50	160	30	34.5	-6	52.90	257	23	28.5						
A 14		48	44	340	33	12.9	-6	52.91	257	26	7.5						
												257	25	14.8	-26.8	63.7	-0.91
A 21		50	42	340	33	51.6	-6	52.95	257	26	48.6						
A 22		52	21	160	31	35.6	-6	52.98	257	24	34.4						
												257	25	14.1	-27.4	65.6	-1.22
A 23		54	28	160	30	22.9	-6	53.00	257	23	22.9						
A 24		56	25	340	33	11.1	-6	52.99	257	26	10.5						
												257	25	13.7	-27.0	66.0	-1.15
A 31	4	58	37	340	33	47.6	-6	53.02	257	26	48.8						
A 32	5	0	28	160	31	26.7	-6	53.10	257	24	32.7						
mean												257	25	14.3	-27.0	64.5	-1.08
range												0	0	1.0	0.8	3.0	0.31
T.mark No2												257	45	7.6	->s.d.	1.6	
T2(reduce)												0	19	37.9			
T2-T2(red)												257	25	29.7			
D-Dop												0	0	-15.4			

observed

semi-fixed

date 1989 11 14 obs. Uwai rec. Fukushima assumed zero offset 0.0nT

Inclination

	UT h	m	s	B °	'	"	Iop °	'	nπ ± B-Iop	→ average	ε	S0 nT
B 11	5	8	31	49	17	16.5	48	75.42	111.3			
B 12		9	49	229	17	13.6	48	75.41	109.0			
										173.9	63.8	-0.18
B 13		11	32	310	40	37.9	48	75.40	238.2			
B 14		13	6	130	40	38.8	48	75.40	237.3			
										173.2	64.5	-0.09
B 21		14	50	49	17	12.4	48	75.39	109.0			
B 22		16	8	229	17	12.4	48	75.40	108.4			
										175.0	66.3	-0.41
B 23		18	2	310	40	29.0	48	75.44	244.7			
B 24		19	42	130	40	33.9	48	75.47	237.9			
										176.0	65.3	-0.61
B 31		21	26	49	17	22.2	48	75.49	112.8			
B 32		23	10	229	17	19.3	48	75.51	108.7			
mean										174.5	65.0	-0.32
range										2.8	2.5	0.52
reduce										179.4		
I-Iop										-4.9		

Figure 2 Example of the calculation sheets.

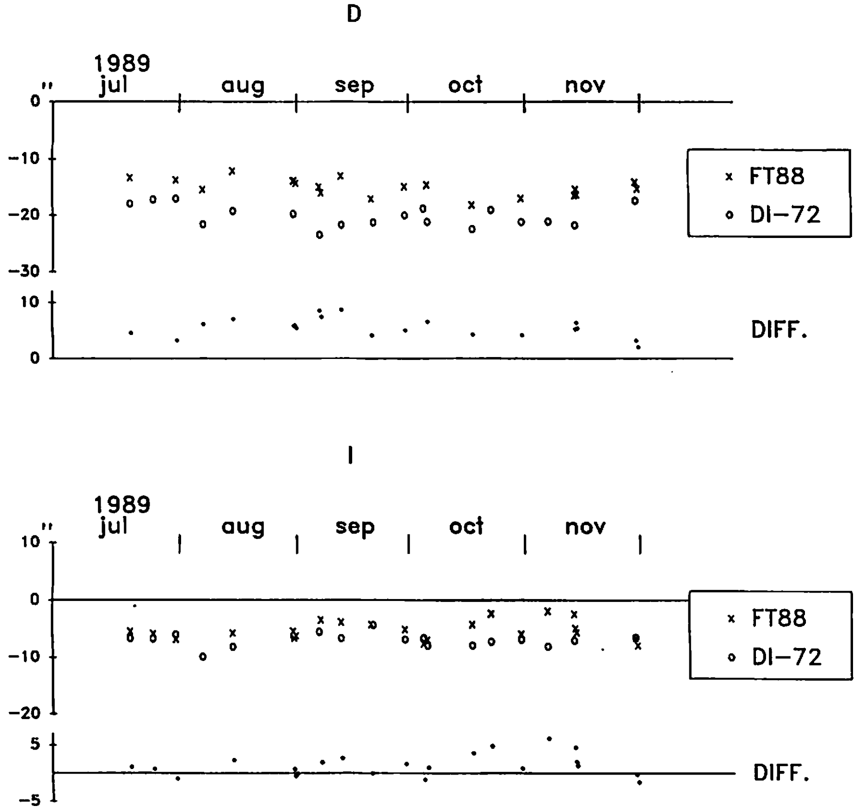

Figure 3 Calibration values for the optical pumping magnetometer system in the period from July to November, 1989.

we can not divide them to the two sources, because the difference on the two pillars is not enough examined yet.

And then, we observed with the two instruments synchronously on the pillars which the difference of D and I were examined better, to confirm the difference with the two instruments and certainty of individual values. In this case, one set of the observation is four times repetition of such D-and I-measuremet as mentioned in "Observation method" section. We got one observation set on June 16,1990 and on June 25,1990; and got four sets on July 17,1990. Table 2.1-2.3 and Figure 4 show the obtained data. The values with FT88 or DI-72 are the calibration values for the optical pumping magnetometer system. The standard deviations of the sighting of the azimuth reference mark were 1.6″ with FT88 (n=64), 2.3″ with DI-72 (n=88) in the case on July 17.

The differences of the values have a similar character to that in the above case. The reduction values were measured with the error about 3″ for D in 1976; and about 2″ for I. But as the DI-72 has been fixed on the pillar since then, the secular variations of the D-and I-reduction values have not been measured. So, there is the possibility that the reduction has not enough accuracy.

Table 2.1 Calibration values for the optical pumping magnetometer system on June 16, 1990.

1990.Jun.16	D			I		
	FT88	DI-72	DIFF.	FT88	DI-72	DIFF.
time(UT)	″	″	″	″	″	″
00:46-00:56	-18.4	-22.9	4.5		-6.7	
01:02-01:09	-18.5	-21.8	3.3		-4.5	
01:11-01:22	-20.8	-21.5	0.7		-4.3	
01:24-01:29	-20.1	-19.7	-0.4		-4.3	
01:39-01:43		-24.5		-2.4	-5.5	3.1
01:45-01:50		-24.8		-2.8	-6.6	3.8
01:52-01:56		-24.9		-1.0	-7.5	6.5
01:58-02:03		-23.5		-2.7	-6.6	3.9
n	4	8	4	4	8	4
mean	-19.45	-22.95	2.02	-2.23	-5.75	4.33
s.d.	1.19	1.85	2.26	0.83	1.27	1.49

Table 2.2 Calibration values for the optical pumping magnetometer system on June 25, 1990.

1990.Jun.25	D			I		
	FT88	DI-72	DIFF.	FT88	DI-72	DIFF.
time(UT)	″	″	″	″	″	″
05:03-05:11	-21.3	-26.2	4.9		-8.1	
05:14-05:20	-20.2	-26.9	6.7		-5.2	
05:23-05:30	-20.4	-27.0	6.6		-7.5	
05:32-05:39	-19.5	-24.5	5.0		-7.0	
05:52-05:58		-25.4		-2.4	-4.5	2.1
06:00-06:06		-24.5		-2.5	-5.5	3.0
06:08-06:13		-23.6		-2.3	-7.7	5.4
06:16-06:21		-23.5		-2.9	-5.3	2.4
n	4	8	4	4	8	4
mean	-20.35	-25.20	5.80	-2.53	-6.35	3.23
s.d.	0.74	1.39	0.98	0.26	1.37	1.50

Each of values for D and for I with FT88 was more stable than that with DI-72. On July 17, the standard deviations with FT88 were only 0.6″ for D and for I, so the observed values were almost constant. Baseline values for a 3-axes fluxgate magnetometer in Kakioka calculated from the same observation values show a similar result (not figured). Therefore the optical pumping magnetometer, the 3-axes fluxgate magnetometer and the FT88 must have operated stably for the period. In contrast to them, the standard deviations with the DI-72 were 2.2″ for D and 1.4″ for I; these are obviously larger than those with FT88. The difference of the values with the two instruments was affected by the variation of the value with the DI-72. On July 17, the mean value for D with the DI-72 in each observation set was -26.86″ (s.d. 0.59″), -30.50″ (s. d. 1.10″), -32.46″(s. d. 0.84″) and -30.55″ (s. d. 0.71″). Though the mean value varied, the s. d. were rather small. So the source of the variation was in the instability like a diurnal variation of the base of DI-72 and/or in that of the pillar. Though the s. d. with the DI-72 was larger than that with FT88 in this case, the s.d. with the DI-72 is about 0.8″ for D and for I in the usual observation on an average. So, the reliabilities of the values with the two instruments are almost equal to each other.

Table 2.3 Calibration values for the optical pumping magnetometer system on July 17, 1990.

1990.Jul.17	D			I		
	FT88	DI-72	DIFF.	FT88	DI-72	DIFF.
time(UT)	″	″	″	″	″	″
00:20-00:28	-22.0	-27.7	5.7		-6.3	
00:30-00:37	-21.7	-26.7	5.0		-5.9	
00:40-00:46	-22.6	-26.3	3.7		-6.5	
00:48-00:54	-22.2	-26.2	4.0		-6.8	
01:11-01:16		-26.7		-1.2	-4.2	3.0
01:18-01:23		-26.9		-2.6	-4.4	1.8
01:25-01:29		-26.6		-3.6	-6.0	2.4
01:31-01:36		-27.8		-3.2	-4.7	1.5
01:56-02:01	-22.1	-30.2	8.1		-2.5	
02:02-02:07	-22.3	-28.6	6.3		-6.5	
02:09-02:16	-23.1	-30.0	6.9		-5.1	
02:18-02:24	-23.3	-29.9	6.6		-6.9	
02:33-02:37		-31.3		-2.1	-7.9	5.8
02:39-02:43		-32.3		-3.0	-4.8	1.8
02:45-02:50		-31.0		-2.1	-5.7	3.6
02:52-02:56		-30.7		-2.0	-4.5	2.5
04:41-04:48	-23.7	-32.9	9.2		-2.4	
04:50-04:58	-23.0	-31.7	8.7		-5.7	
05:00-05:06	-23.7	-33.7	10.0		-5.3	
05:08-05:13	-23.6	-32.8	9.2		-6.7	
05:21-05:27		-33.3		-2.1	-3.0	0.9
05:29-05:33		-31.9		-3.0	-5.0	2.0
05:35-05:39		-32.1		-2.1	-5.4	3.3
05:41-05:45		-31.3		-2.0	-3.2	1.2
06:38-06:43	-23.0	-31.1	8.1		-6.8	
06:45-06:50	-23.3	-30.6	7.3		-7.3	
06:51-06:56	-22.9	-29.9	7.0		-6.8	
06:58-07:03	-22.6	-31.4	8.8		-6.5	
07:11-07:15		-31.3		-2.6	-4.5	1.9
07:16-07:21		-29.9		-3.0	-6.0	3.0
07:22-07:26		-30.7		-2.2	-6.2	4.0
07:27-07:31		-29.5		-2.8	-7.2	4.4
n	16	32	16	16	32	16
mean	-22.82	-30.09	7.16	-2.48	-5.52	2.69
s.d.	0.63	2.21	1.88	0.60	1.41	1.30

Summary

The theodolite was nonmagnetic without remodeling. Some fluxgate magnetometers are influenced by surrounding conductors; these are not suitable for the present experiment. Measurement is so sensitive to the position change of the sensor that the sensor should be fixed firmly to the telescope of the theodolite. The cable connected to the sensor requires to be light and flexible not to shift the sensor. After consideration about such conditions, a combination of a fluxgate magnetometer and a theodolite makes it possible to observe D and I with a certain accuracy come from those of the two. The comparison with the standard instrument of Kakioka shows;

1. The standard deviations both with the two instruments were less than 2″ in an observation set for D or I.
2. For five months, the variation range of the difference of the values with the two was several seconds of arc for D or I, including systematic errors by observers.
3. The observation procedure does not require skill.

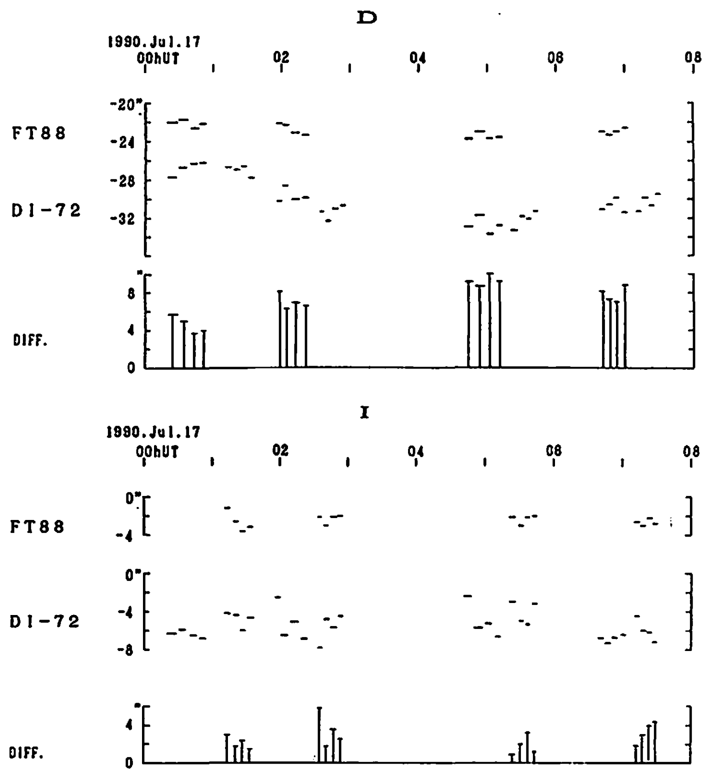

Figure 4 Calibration values for the optical pumping magnetometer system on July 17, 1990.

As a result of this experiment, we found that this type of instrument had high performance to be able to replace traditional ones.

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フラックスゲート磁力計を搭載した経緯儀による偏角，伏角の試験観測

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概　　要

非磁性の経緯儀にフラックスゲート磁力計を取り付け，偏角，伏角を測定する実験をした．初期の経験から，センサーを導体との干渉の小さいものに代える等の改良を加えた．この測器を5ヶ月間固定台に置き，測定をした．光ポンピング磁力計の較正値を作り，柿岡の基準磁気儀の同日の観測と比較した結果，両者の差およびその変動は小さかった．そこで地点差のより明らかな台を用いて両者の同時観測を行った．その結果両測器の差はたいへん小さく，試験器は基準磁気儀とほぼ同等の性能があることが確認できた．