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Measurement of Alternating Field Sensitivity of Fluxgate Magnetometer MB 162

by

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1. Introduction

A recent striking progress in microprocessor technology has facilitated recording geomagnetic data every second. The Kakioka Magnetic Observatory (KMO) started the measurement and recording of one-second value of geomagnetic field at Kakioka without missing by optical pumping magnetometers and minicomputers in 1983. Back in those days such technology was very expensive. Today, one-second geomagnetic data of Chichijima Island is measured by a relatively inexpensive system composed of the combination of a fluxgate magnetometer and PC (Uwai, 1989). Technical experiments are under way to help the Kanoya and Memambetsu Geomagnetic Observatories to start measurement and recording of one-second geomagnetic values.

Induction magnetometers are conventionally used for observation of short-period geomagnetic changes such as geomagnetic pulsations that require one-second resolution. Since a highly sensitive fluxgate magnetometer came to be possible to cover the period ranges formally covered by induction magnetometers fluxgate magnetometers are now used to observe short-period geomagnetic changes. For conventional fluxgate magnetometers, it is enough to determine a sensitivity to direct current components of geomagnetic field (hereafter reffered to as "DC sensitivity") as it was for suspended magnet variometers, but when it comes to be applied to the field of pulsation observation, the characteristics of sensitivity to alternating current components of geomagnetic field (hereafrer, "AC sensitivity") are necessary, particularly those of short periods of less than one minute. But measurement of AC sensitivity of fluxgate magnetometers is only covered by a small number of reports including Yamamoto (1992).

KMO uses the MB 160 and MB 162 fluxgate magnetometers produced by Shimadzu Corporation for observation of three components of geomagnetism. A variety of detailed research has been conducted on the DC sensitivity of those magnetometers (Koike et al. 1990, and Sugawara et al. 1991), but no detailed reports have been written on AC sensitivity characteristics. The following sections of this text report the results of AC sensitivity measurement of the MB 162 magnetometer in order to apply fluxgate magnetometers to observation of short-period geomagnetic changes.

2. Measurement Method

2.1 Outline

The magnetometer used in our research is an MB 162 with serial number 295682, which had been used at Matsuzaki Observation Point in the Tokai area, Central Japan, and the instrment was stored at KMO after repair.

This type of magnetometer has a few slide switches on the rear panel of the control unit, and one of the switches, labeled LPF, is for low-pass filter switching. The switch has four positions, labeled "0.1", "1", "5" and " ". The last two, "5" and " ", are connected by the same wiring, meaning that there are three effective positions, "0.1", "1" and "5". These labels indicate that the characteristic frequencies of low-pass filter are 0.1 Hz, 1 Hz and 5 Hz, respectively. If LPF has a different characteristic frequency, the AC sensitivity should naturally come out different. Therefore, we measured AC sensitivity for all three positions.

The MB 162 produces two analog outputs. Since the output that is generally used for observation at KMO is one with a higher output voltage (about 10 V at 500 nT for direct current component of magnetic field), sensitivity measurement was carried out for this output.

Sensitivity measurement is defined as the inspection of what voltage (output voltage) is obtained relative to an applied magnetic field (input magnetic field). Therefore, it is extremely important to create and apply an accurately controlled magnetic field. KMO has two large triaxial rectangular coils in the calibration house (Sano et al. 1972, Yanagihara et al. 1973), and that of the west pillar was used to create a magnetic field for our measurement. This coil makes a uniform magnetic field of about 30 cm at its center and can create a magnetic field in three orthogonal directions (H axis, Z axis, and D axis) at the same time. As shown in Fig. 1, the coil and the resistance are connected in series and a voltage generated by a function generator is applied to the coil to create the magnetic field. The amount of resistance R is measured in advance and measuring the voltage V at both ends of the resistance allows calculation of the current I that flows through the circuit. The current I is then multiplied by the coil constant of each axis of the rectangular coil (K_h, K_z, and K_d) to calculate the magnitude of the magnetic field applied to each axial direction.

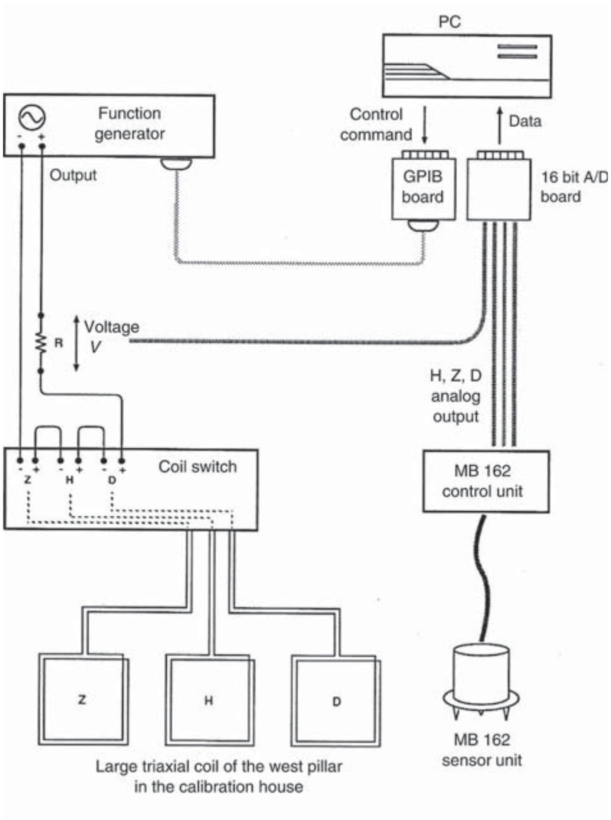

Fig. 1 Outline of the measuring system

The sensor of the MB 162 put at the center of the coil measures the magnetic field, and converts it to voltage (analog output). Therefore, measurement for both the input magnetic field and the analog output can be made by measuring the voltage. For this step of voltage measurement, a PC was used into which a commercially available 16 bit A/D conversion board was built.

For measurement of AC sensitivity, the phase difference between the input and output also has great significance, as does the input-output ratio (gain). It is best to measure the input and output simultaneously to measure the phase difference. Although there is another approach, which is to measure the input and the output separately and compare them later, the approach is effective only when the clocking accuracy of each data recording is sufficiently high. Considering the available equipment and the ease of measurement, it was decided that the input and output should be simultaneously measured, and all the measuring equipment and the magnetometer shown in Fig. 1 were put in the calibration house where measurement was made.

2.2 Measurement of the axial direction

At the first of sensitivity measurement, the direction of each axis of the magnetometer should be adjusted in the direction of the corresponding coil axis. Direction adjustment is described in detail in Sugawara et al. (1991). Even though the directions of the magnetometer's axes are adjusted to those of the coil's axes extremely carefully, when a magnetic field is applied to an axis of the coil, the magnetic field of orthogonal components measured by the magnetometer will not come out as zero. This is presumably because of (1) a discrepancy in the axial direction due to errors in coil assemblage or installation of the axes of the magnetometer or (2) the directionality of each axis of the magnetometer. The latter indicates that the output will not be zero when a magnetic field is applied to the direction perpendicular to the axis of the sensor if that axis is sagging or bending. But this phenomenon has not been quantitatively verified and it is generally assumed that no such effect occurs. Regarding the direction error of the coil in cause(1) mentioned above, the research by Uwai (1990) revealed that the error in orthogonality of each axis of the coil is about 5', and it can be corrected in data processing, as the amount itself is not large. Any remaining amount that does not become zero may be called crosstalk, and it is generally interpreted as an error in the installation direction of each axis of the magnetometer. It is a matter of course that when crosstalk is large, it prevents a highly reliable AC sensitivity measurement. Thus, crosstalk should be measured after axial direction adustment. As crosstalk is interpreted as an error in axial direction of the magnetometer, "crosstalk measurement" is also referred to as "axial direction measurement".

What is important about crosstalk is that once crosstalk is measured after axial adjustment, one can separate the contribution of the magnetic field of each axis by post-measurement processing even when a magnetic field is simultaneously applied to the three axes of the coil. This advantage allows simultaneous measurement of AC sensitivity of the three components of the magnetometer by applying a magnetic field to the three axes simultaneously, thereby reducing the measurement time to one third.

Axial direction measurement is made almost in the same way as that for DC sensitivity measurement. A magnetic field is applied to the three axes of the coil sequentially one by one, and the voltage output for each of the three components of the magnetometer is measured. In our measurement, a rectangular wave of a period of 20 seconds was used for a magnetic field.

2.3 Measurement of AC sensitivity

Given a magnetic field that changes with a sine wave of a certain period, if it is within the measurable range, it produces the output voltage of a sine wave of the same period. Our AC sensitivity measurement was made by measuring the amplitude and phase of both of these sine waves.

The measurement period was set to the range from 0.01 to 100 sec. (100 Hz to 0.01 Hz of frequency). The most noteworthy is the range of periods from below 60 sec. to 1 sec., which will also be necessary to measure one-second values, but it is necessary to measure even shorter periods (higher frequencies) in order to evaluate the influence of aliasing during data sampling. The characteristics of the frequencies around 50 Hz (0.02 sec.), which are expected to be subject to high noise levels, are particularly important. Considering these, the above period range was set to ensure more than enough coverage. The periods used for our measurements are shown in Table 1. The data sampling intervals and the number of samples taken are also shown in the table.

Since the coil constant for each axis, K_h, K_z, and K_d, is 11.222, 10.869, and 11.628 (nT/mA) (Koike et al. 1990), a magnetic field of about 100 nT was applied assuming $R \approx 1$ kΩ and voltage $V \approx 9$V.

It takes about one hour to take this set of measurements. As LPF positions need to be switched, a total of three sets of measurements

Table 1 Measuring period

Period (sec)	Frequency (Hz)	Number of data	Sampling interval (msec)
0.01	100	200	1
0.015	66.66667	200	1
0.02	50	200	2
0.03	33.33333	200	2
0.04	25	200	4
0.06	16.66667	200	4
0.1	10	200	10
0.15	6.66667	200	10
0.2	5	200	20
0.3	3.33333	200	20
0.4	2.5	200	40
0.6	1.66667	200	40
1	1	200	100
1.5	0.66667	200	100
2	0.5	200	200
3	0.33333	200	200
4	0.25	200	400
6	0.16667	200	400
10	0.1	200	1000
15	0.06667	200	1000
20	0.05	200	1000
30	0.033333	300	1000
40	0.025	400	1000
60	0.016667	600	1000
100	0.01	1000	1000

are necessary, which means that it takes quite a long time. Therefore, in order to ensure efficiency of the measurements and to save labor, the switchover of function generator frequencies was controlled by GPIB from the PC, and the majority of other operations such as recording of data and processing for measurement were automated by utilizing.

3. Processing of Measured Data

Sine waves are applied as voltage V for the creation of an input magnetic field. With the period of this sine wave as T, the input voltage at time t, $V(t)$, is given by:

$$V(t) = C_v \cos\left(\frac{2\pi}{T}\right) t + S_v \sin\left(\frac{2\pi}{T}\right) t + O_v \qquad (1)$$

or

$$V(t) = A_v \cos\left(\frac{2\pi}{T} t + \phi_v\right) + O_v \qquad (2)$$

where C_v, S_v, O_v, A_v, and ϕ_v are parameters to be determined by measurement. The following relationships are established among the parameters:

$$A_V = \sqrt{C_v^{\ 2} + S_v^{\ 2}} \qquad (3)$$

$$\phi_V = -\tan^{-1}\left(\frac{S_v}{C_v}\right) \qquad (4)$$

Although the two equations express the same sine waves, Equation (1) is more useful for determining the parameters from the measured data because the parameters are linear and it is easier to apply the method of least squares. Equation (2) is more useful for calculating the amplitude ratio or phase difference between input and output because the equation contains the amplitude of V, or A_v, and phase ϕ_v as parameters. Now the parameters should be calculated using Eq. (1) based on the measured data and converted to the parameters in Eq. (2) (amplitude and phase) using Eqs. (3) and (4). The magnetic field applied to the H axis of the coil at time t, or $h(t)$, is given by resistance R and coil constant K_h as follows:

$$h(t) = \frac{K_H}{R} V(t) \qquad (5)$$

The same applies to the magnetic field for the Z and D axes.

H(t), the output voltage of the H component of the magnetometer at time t, which is measured simultaneously with V, can be similarly treated to calculate amplitude A_h and ϕ_h phase. Consequently, the gain G_h and phase difference (progress of the phase) ϕ_H of the H component are given as follows:

$$G_H = \frac{RA_H}{K_H A_v} \qquad (6)$$

$$\Delta\phi_H = \phi_H - \phi_v \qquad (7)$$

as they are for the Z and D components.

When parameters are estimated by Eq. (1), in ordr to reduce the influence of the noise that is mixed into the measurement data, the measured data should be segmented into each period, and parameters for each segment should be calculated. Parameters of a segment greatly suffering from noise will come out quite different from those of other segments. Such parameters, if any, will be discarded and the parameters of segments that are thought to be less affected by noise will be put together and averaged to determine the parameters. Using this approach, we can often obtain results that are more plausible than the parameters obtained by applying the least squares method to all measured data as one segment. In our measurement data, there were almost no segments that needed be discarded, which is fortunate because the input magnetic field was relatively large (amplitude of about 100 nT) and the geomagnetic variation was rather quiet.

4. Results

The result of processing data, that is, the gain and the progress of the phase, are shown in Tables 2 through 4. These tables indicate that the short-period side characteristics differ depending on the position of the LPF. But there are no major differences between the three components, or H, Z and D, when the LPF position is the same. Now the characteristics of H, as a representative component of the three, for each position of the LPF, are shown in Figs. 2, 3, and 4.

In each of the figures, the gain is about 20 mV/nT and the progress of the phase about 0°

Table 2 Results of measurement for the LPF "0.1" (gain and the phase progress)

	H		Z		D	
Period (sec)	Gain (mV/nT)	Phase (deg.)	Gain (mV/nT)	Phase (deg.)	Gain (mV/nT)	Phase (deg.)
0.01	0.0031	-360.3	0.0012	-379.3	0.0007	-356.3
0.015	0.0024	-312.9	0.0018	-278.6	0.0024	-258.5
0.02	0.0035	-279.5	0.0032	-259.8	0.0054	-248.4
0.03	0.0122	-232.2	0.0139	-239.1	0.0172	-227.0
0.04	0.0275	-212.5	0.0247	-222.2	0.0382	-207.4
0.06	0.0714	-181.0	0.0628	-190.1	0.0955	-172.9
0.1	0.1663	-145.0	0.1519	-151.5	0.1938	-135.5
0.15	0.2668	-126.6	0.2456	-131.7	0.2877	-118.1
0.2	0.3743	-116.6	0.3470	-121.0	0.3895	-109.8
0.3	0.5707	-106.7	0.5396	-110.9	0.5788	-101.9
0.4	0.7586	-101.6	0.7233	-105.7	0.7588	-97.9
0.6	1.1366	-95.9	1.1085	-99.4	1.1326	-93.3
1	1.9030	-90.1	1.8900	-92.7	1.8871	-88.5
1.5	2.8237	-85.7	2.8346	-87.5	2.7961	-84.6
2	3.7556	-82.1	3.7780	-83.5	3.7107	-81.2
3	5.5122	-76.0	5.5641	-76.8	5.4473	-75.4
4	7.1493	-70.6	7.2189	-71.2	7.0666	-70.2
6	9.9671	-61.4	10.0590	-61.5	9.8509	-61.0
10	13.8815	-47.2	13.9625	-47.1	13.7123	-47.0
15	16.5207	-35.6	16.5703	-35.4	16.3127	-35.4
20	17.8656	-28.2	17.8969	-28.0	17.6415	-28.1
30	19.0682	-19.6	19.0616	-19.5	18.8235	-19.6
40	19.5488	-15.0	19.5364	-14.8	19.2951	-14.9
60	19.9192	-10.1	19.8884	-10.0	19.6629	-10.0
100	20.1190	-6.1	20.0835	-6.0	19.8647	-6.1

Table 4 Results of measurement for the LPF "5" (gain and the phase progress)

	H		Z		D	
Period (sec)	Gain (mV/nT)	Phase (deg.)	Gain (mV/nT)	Phase (deg.)	Gain (mV/nT)	Phase (deg.)
0.01	0.0596	-273.1	0.0407	-281.7	0.0726	-273.7
0.015	0.1730	-253.7	0.1179	-261.2	0.2130	-253.9
0.02	0.4181	-242.6	0.2528	-247.3	0.4722	-241.0
0.03	1.1555	-215.0	0.8825	-225.4	1.5036	-214.3
0.04	2.3945	-192.6	1.9433	-203.6	3.1855	-190.1
0.06	5.5940	-155.6	4.8784	-164.8	7.2609	-148.1
0.1	11.0067	-108.4	10.0018	-114.4	12.7034	-98.3
0.15	14.7265	-77.7	13.5104	-82.2	15.7850	-69.1
0.2	16.6651	-60.2	15.3690	-64.3	17.2978	-53.2
0.3	18.4370	-41.4	17.1858	-45.1	18.6424	-36.4
0.4	19.1744	-31.4	18.0701	-35.1	19.1949	-27.5
0.6	19.7429	-21.2	18.9542	-24.5	19.6132	-18.5
1	20.0541	-12.8	19.6371	-15.4	19.8422	-11.2
1.5	20.1512	-8.5	19.9223	-10.4	19.9146	-7.4
2	20.1904	-6.4	20.0398	-7.9	19.9424	-5.6
3	20.2126	-4.3	20.1244	-5.3	19.9559	-3.7
4	20.2223	-3.2	20.1535	-4.0	19.9607	-2.8
6	20.2307	-2.1	20.1777	-2.7	19.9684	-1.9
10	20.2321	-1.3	20.1878	-1.6	19.9652	-1.1
15	20.2379	-0.9	20.1913	-1.1	19.9741	-0.7
20	20.2354	-0.6	20.1868	-0.8	19.9725	-0.6
30	20.2441	-0.4	20.1766	-0.5	19.9598	-0.3
40	20.2301	-0.3	20.1829	-0.4	19.9609	-0.3
60	20.2377	-0.2	20.1854	-0.3	19.9654	-0.2
100	20.2153	-0.1	20.1960	-0.1	19.9574	-0.1

Table 3 Results of measurement for the LPF "1" (gain and the phase progress)

	H		Z		D	
Period (sec)	Gain (mV/nT)	Phase (deg.)	Gain (mV/nT)	Phase (deg.)	Gain (mV/nT)	Phase (deg.)
0.01	0.0066	-295.0	0.0044	-297.9	0.0074	-277.7
0.015	0.0178	-265.5	0.0115	-271.4	0.0219	-259.7
0.02	0.0449	-243.9	0.0288	-258.0	0.0555	-247.3
0.03	0.1264	-226.8	0.0960	-236.9	0.1653	-226.1
0.04	0.2695	-209.0	0.2174	-219.3	0.3579	-205.6
0.06	0.6628	-178.4	0.5735	-186.7	0.8578	-170.2
0.1	1.5147	-142.2	1.3511	-147.1	1.7208	-131.4
0.15	2.4592	-120.5	2.1993	-124.1	2.5878	-111.4
0.2	3.3425	-108.5	2.9904	-111.8	3.3922	-101.0
0.3	5.0094	-94.3	4.5117	-97.8	4.9395	-89.1
0.4	6.5584	-85.0	5.9670	-88.7	6.4007	-81.2
0.6	9.2784	-72.0	8.6202	-75.8	9.0037	-69.8
1	13.2069	-54.8	12.6148	-58.3	12.8388	-53.9
1.5	16.0018	-41.4	15.5632	-44.3	15.6291	-41.1
2	17.5003	-32.9	17.1779	-35.3	17.1476	-32.7
3	18.8685	-23.0	18.6763	-24.8	18.5498	-23.0
4	19.4285	-17.6	19.2955	-18.9	19.1307	-17.6
6	19.8612	-11.9	19.7760	-12.8	19.5817	-11.9
10	20.0954	-7.2	20.0403	-7.7	19.8223	-7.2
15	20.1712	-4.8	20.1228	-5.2	19.9023	-4.8
20	20.1992	-3.6	20.1540	-3.9	19.9276	-3.6
30	20.2046	-2.4	20.1575	-2.6	19.9351	-2.4
40	20.2165	-1.8	20.1757	-2.0	19.9543	-1.8
60	20.2140	-1.2	20.1800	-1.3	19.9854	-1.2
100	20.2324	-0.7	20.2027	-0.8	19.9718	-0.7

near the period of 100 sec. in the long-period area. This value of gain is equal to the value expected from the DC sensitivity. Qualitatively speaking, the gain decreases as the period shortens in the short-period area (high frequency area) for all of them. In either case, the progress of the phase is characterized by changes that gradually move away from zero, and values were always in the negative as far as within the range of measurement. In other words, the phase lag always takes a positive value. We will use the phase "lag" when phase is discussed below. Although the characteristics of the short-period side share some similarities, their behavior varies depending on LPF.

For the "0.1" position of LPF (Fig. 2), the gain is almost constant in the long-period side from 10 sec. (0.1 Hz), and the gain reduces from periods of 10 sec. to 0.1 sec. (0.1 Hz to 10 Hz) at a rate of reduction that halves as the period is halved (−6 dB/oct). In the shorter period ranges from 0.1 sec. to 0.01 sec. (10 Hz to 100 Hz), the gain reduces at a greater rate. In the range 0.02 sec. and below (50 Hz and higher), measurement precision may not be sufficient because the output voltage is as small as 0.1 nT in the magnetic field onverted by DC sensitivity. For the phase lag, it is about 45° for a period of 10 sec. and about 90° for a period of 1 sec. The phase shift of about 10° for a period of one min. or 60 sec. is very large. The rate of phase increase is large in the range from 0.1 sec. to 0.01 sec. (10 Hz to 100 Hz in frequency).

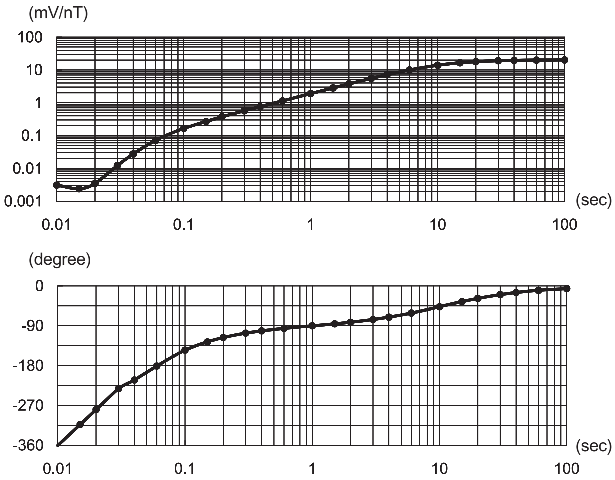

Fig. 2 Gain (top) and the phase progress (bottom) for the LPF “0.1”

For the “1” position of LPF (Fig. 3), the gain is almost constant from periods of 1 sec. to 100 sec. The gain decreases at a rate of −6 dB/oct with a decrease in period. in the range from 1 sec. to 0.1 sec. (1 Hz to 10 Hz). The reduction rate of the gain is greatest in the range from 0.1 sec. to 0.01 sec. (10 Hz to 100 Hz). The phase lag is about 55° for a period of 1 sec. In the range from 0.1 sec. to 0.01 sec. (10 Hz to 100 Hz), the phase lag gradually increases.

For the “5” position of the LPF (Fig. 4), the gain is almost constant from 100 sec. to 0.2 sec. In periods shorter than that, the gain decrement is about one fifth or sixth for every halving of the period (−15 dB/oct). The gain for a period of 0.02 sec. (50 Hz) is about one 50th the gain of the DC

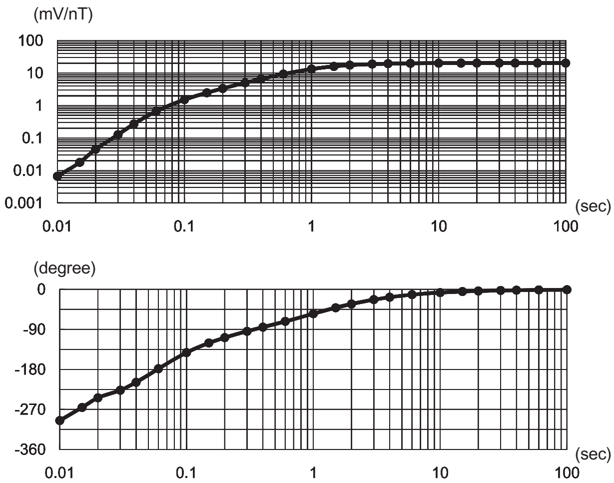

Fig. 3 Gain (top) and the phase progress (bottom) for the LPF “1”

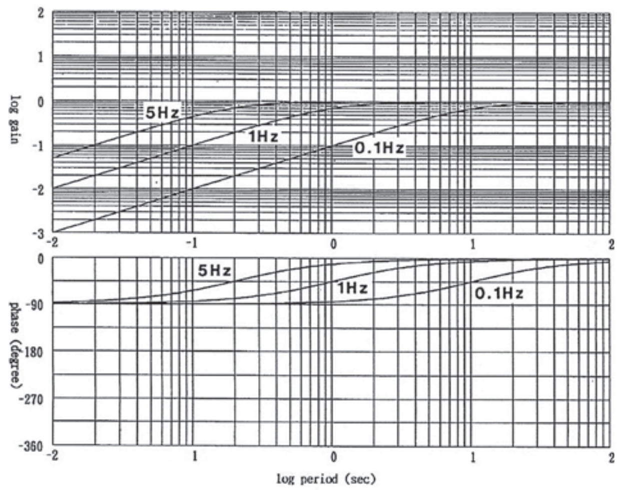

Fig. 5 Gain (top) and the phase progress (bottom) of the CR filter (f_c = 0.1, 1, 5 Hz)

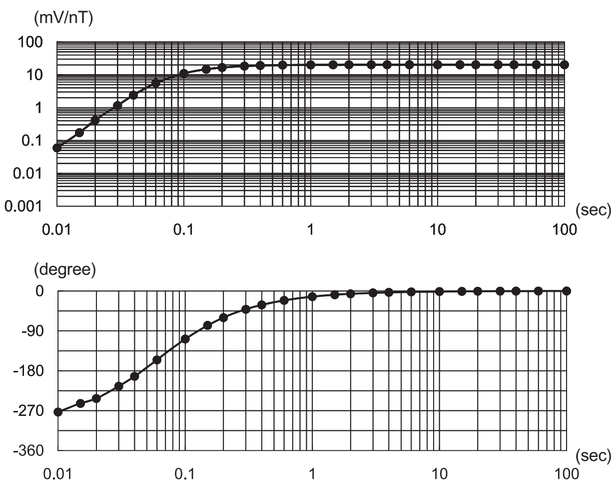

Fig. 4 Gain (top) and the phase progress (bottom) for the LPF “5”

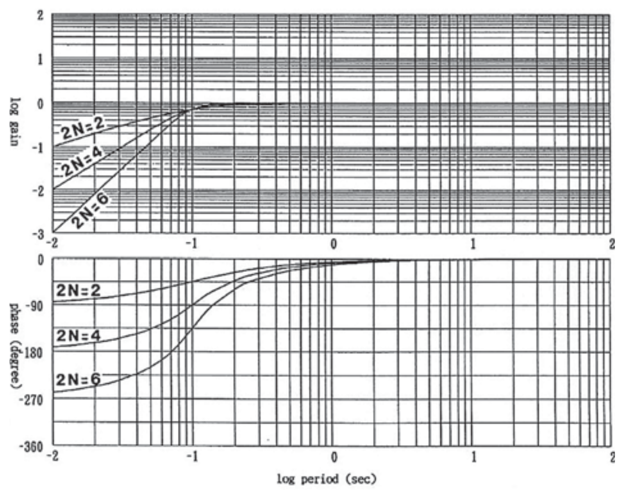

Fig. 6 Gain (top) and the phase progress (bottom) of the Butterworth filter ($2N$ = 2, 4, 6)

component. The phase lag is about 60° for a period of 0.2 sec. (50 Hz).

One of the simplest low-pass filters realized by an analog circuit is a CR filter which combines a capacitor and resistor. The characteristics of the CR filter are compared with those of the MB 162. Figure 5 shows the gains and phases of the CR filter at a characteristic frequency (f_c) of 0.1 Hz, 1 Hz, and 5 Hz. At the "0.1" position of the LPF, the characteristics of the gain for a period of 0.1 sec. and higher (10 Hz and below) and the phase for a period of not less than 1 sec. (not more than 1 Hz) are almost the same as those of the CR filter at f_c = 0.1 Hz. At the "1" position, the characteristics of the gain for a period of 0.1 sec. or more (10 Hz or lower) and the phase for a period of 1 sec. or more (1 Hz or lower) are almost the same as those of the CR filter at 1 Hz of f_c. For the "5" position, the gain is different from what is expected of the CR filter at 5 Hz in f_c even in the region of 0.1 sec. or higher periods (10 Hz or lower frequencies).

At either position, the characteristics in the region of 0.1 sec. or lower periods (10 Hz or higher frequencies) are different from those of the CR filter. For the characteristics of MB 162, the reduction of gain in this range is larger, as is the phase lag. It seems necessary to think a different low-pass filter that has sharper cut-off characteristics.

The type of low-pass filter that has sharper cut-off characteristics and yet is as flat in the passband (no ripples) as the MB 162 is the Butterworth filter. Its characteristics of gain relative to frequency f, $G(f)$, are expressed as:

$$|G(f)|^2 = \frac{1}{1+\left(\frac{f}{f_c}\right)^{2N}} \quad (8)$$

For comparison, the characteristics for f_c = 10 Hz and $2N$ = 2, 4, and 6 are shown in Fig. 6. The phase behavior is clearly different from that of MB 162, and the reduction rate of gain does not match either.

5. Conclusion

AC sensitivity for the MB 162 was measured, and the frequency characteristics for periods 0.01 sec. to 100 sec. were clarified for the three positions of the low-pass filter. The characteristics of the low-pass filter for all positions have been clarified, which are that the gain change is flat and the phase lag is almost none in the long-period side and that the gain reduces with a decrease in period and the phase lag increases in the short-period side. Particularly for the two positions of the LPF, "0.1" and "1", the characteristics of the MB 162 in the region of 0.1 sec. or longer in period (10 Hz or lower in frequency) are almost the same as those obtained from the CR filter. For shorter periods, or under 0.1 sec. (10 Hz or more), sharper low-pass characteristics are identified, but it is unknown to what circuit those characteristics are equivalent.

When the data are sampled at an interval of one second for geomagnetic observation, it is necessary to remove the components of the period below 2 seconds in advance to prevent aliasing. If it were conducted with the MB 162, there would be no choice but to choose the "0.1" LPF position as far as can be determined based on the characteristics obtained from our measurement. This position is also often used for measurement of one-minute geomagnetic data. But our measurement found that this position causes a considerably large phase lag even for a period of one minute. Considering the magnitude of the lag, some phase compensation would be necessary in the region below periods of 1 min. in the case that the one-second geomagnetic data obtained using this position are used for MT in conjunction with the independently obtained earth current data.

Considering the variety of ways geomagnetic data are used, it is desired that the data used for one-second geomagnetic data contain small enough phase lags, hopefully down to a period of a few seconds. In terms of the characteristics of the MB 162, measurement with the LPF "1" position, and "5" position, is desired. But when sampling at an interval of one second is done at those positions in a normal way, aliasing could occur. Some means to prevent it are also necessary. For example, over-sampling of data (10 Hz sampling, for instance) should be conducted, components of a period of 2 seconds or under be removed by digital filtering, and the one-second average be calculated. Or resampling of 1 Hz should be conducted to obtain one-second data. These procedures may serve as solutions to eliminate aliasing.

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