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Introduction to our New System: Magnetometer for Wide Frequency Range

by

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Abstract

During 1995 and 1996, Kakioka Magnetic Observatory developed a new measurement system of magnetometer for wide frequency range at both two branches, Memambetsu and Kanoya and we just started to operate them. By the use of one single highly sensitive fluxgate-magnetometer as a sensor which is applicable for low-frequency to high-frequency ranges, we can obtain digital values at every 0.1-second and 1-second. Data collections are carried out using a personal computor basically. At Kakioka, we reconstructed our high-sensitivity fluxgate-magnetometer which has been operated for 1-second value measurement since 1990, and added a data collection unit in such a way that we can obtain 0.1-second values as well. We can draw a magnetogram-like picture of which time-response is better than that by so-called variometer by plotting these 1-second values of the three components. Similarly, we can detect rapid variations such as magnetic pulsations easily and precisely by plotting these 0.1-second values of the three components. Accordingly, we terminated both the variometer measurements and the observation with induction coils at three observatories. These digital values of 0.1-second and 1-second are expected to be utilized in every field of geomagnetism.

1. Introduction

Geomagnetic observation is broadly divided into and consists of absolute observation, variation observation and geomagnetic pulsation observation. In absolute observation, a magnetic theodolite (Type DI-72 theodolite) at Kakioka and an FT (fluxgate-magnetometer theodolite) type theodolite at both Memambetsu and Kanoya Magnetic Observatories are used to measure the direction (dip and declination) of geomagnetic field and a proton magnetometer is used to measure the magnitude (total magnetic force) of geomagnetic field. For variation observation, mainly fluxgate magnetometers but also suspended magnet type variometers and vector proton magnetometers have been used so far. For geomagnetic pulsation observation, inductive magnetometers have been used. This instrument consists of a sensor made of a metal core with high magnetic permeability wound around with several ten thousand turns of copper wire, an amplifier and a filter.

So far, different observing instruments have been used for variation and geomagnetic pulsation observation. This is because of the difference in period and amplitude of the geomagnetic phenomena to be observed and the technical difficulty in fabricating an instrument that has sufficient accuracy to be commonly used for both modes of observation. However, the technology of geomagnetism measuring instruments has been noticeably improved in recent years, and a fluxgate magnetometer has been fabricated. This instrument has sufficient capabilities to be commonly used for variation and geomagnetic pulsation observation. Thus, it has become possible to construct an efficient observing system using this type of instrument. The Kakioka Magnetic Observatory developed such a system called the “Geomagnetic Variation Observing Equipment” and installed it at Kakioka, Memambetsu and Kanoya, beginning operation in 1995 to 1996.

The geomagnetic variation observing equipment consists of a sensor section and a measurement control, processing and analysis section. The sensor section is made of a high sensitivity fluxgate magnetometer (Abbreviated as FM. To distinguish the FMs at Kakioka, Kanoya and Memambetsu, the two least significant digits of the year of installation are added, so the instrument is called the 90FM at Kakioka, the 95FM at Kanoya and the 96FM at Memambetsu) on which an inclinometer and thermometer are mounted. The measurement control, processing and analysis section receives digital and analog signals from the sensor portion and conducts conversion, processing, recording and analysis of them. Data are all digitized for efficient data processing and analysis as well as for making the data available with higher accuracy. This was accompanied by the ceasing of observation by the suspended magnet type variometer (analog photopaper recording) and inductive magnetometer (analog magnetic tape recording and direct monitor recording), which had been used for many years.

This article presents an outline of the newly installed Geomagnetic Variation Observing Equipment.

2. Sensor section - Highly sensitive fluxgate magnetometer

The 95FM and 96FM are based on the specifications for the 90FM (Tsunomura et al., 1994) installed at Kakioka in 1990 and were fabricated by Shimadzu Corporation. These FMs employ the solenoid 2-core type on each of the 3 axes (H, Z, D). Using a longer core than the usual, stable signals could be successfully obtained and the resolution improved. The sensor has a small built-in inclinometer and thermometer to enable continuous measurement of inclination and temperature. Besides this, it has several additional functions that are not available with the 90FM. The 90FM was upgraded too by incorporating an inclinometer and thermometer anew and otherwise has the same ability as the 95FM and 96FM.

2-1. Configuration and specifications

The major specifications of the sensor section are shown in Table 1. Major improvements over the old 90FM are as follows:

Table 1 Major specifications of the sensor.

Sensor	a. Temperature coefficient	0.5 nT/°C or less
	b. Stability	Within ±0.1 nT/day
	c. Error in axis direction	Within 6’ between axes (see Table 4)
Amplifier	a. Temperature coefficient	0.5 nT/°C or less
	b. Stability	Within ±0.1 nT/day
	c. Measuring range	−600 - +600 nT
	d. Output noise level	0.05 nT or less
	e. Error in sensitivity	Within 0.2%
	f. External sensitivity signal	Sensitivity signal impressed by external voltage signal
	g. Built-in sensitivity signal	±60, ±80, ±100, ±200, ±300 nT (95FM, 96FM) Error within 0.2%
	h. Output signal	Analog 1 DC to 1 Hz/DC to 5 Hz filters Analog 2 DC to 5 Hz filter
	i. Measurement and digital output timing	For each component, A/D conversion 32 times a second, delivered after averaging.
	j. Digital output resolution	0.01 nT
Inclinometer and thermometer	a. Components to be measured	East-west, north-south, temperature

(1) Addition of analog output terminals

To provide measuring capability for pulsating phenomena, analog signal output terminals with a broad pass bandwidth were added.

(2) Addition of external sensitivity signal terminals

The equipment was retrofitted so that a sensitivity signal would be impressed when a known voltage was inputted from the outside. A check for long-term sensitivity variations of the FM had been conducted by the built-in sensitivity signal incorporated in the FM itself. However, this method could not distinguish them from the variations of the reference power used for the built-in sensitivity signal. This weakness was ameliorated in this way.

(3) Broadening of measuring range

To avoid missing observations during large geomagnetic storms, the measuring range was extended from ± 500 nT on the 500-nT range scale to ± 600 nT. The largest magnetic storm since the IGY (1957) was observed (horizontal component range 747 nT at Memambetsu) in the period from March 13 to 15, 1989, but the extended measuring range can measure variations of the same severity without making a scale-out.

(4) Incorporation of built-in inclinometer and thermometer

In geomagnetic observation by the FM, the variations of inclination and temperature of the FM sensor are included in the observed values as an error. To monitor this, the inside of the FM sensor was fitted with an inclinometer and thermometer (AGI-756 by Applied Geomechanics, US). As a result of a magnetic test, the inclinometer and thermometer both had too little magnetism to disturb the measurement.

2-2. Results of FM sensitivity measurement

The FM is designed so that the output value represents the intensity of the measured magnetic field. Strictly speaking, however, it does not always indicate the true value of the magnetic field but deviations from the true value occur in many cases. Therefore, sensitivity calibrating values are required to convert the output values into the true magnetic field values. That is, it is necessary to find the sensitivity calibration values that satisfy:

True intensity of magnetic field = Measured value by FM × Sensitivity calibration value.

For the 3 FMs, the sensitivity calibration (Koike et al., 1990) value was measured using the large rectangular Helmholtz coil at Kakioka for both direct and alternating currents.

2-2-1. DC sensitivity

The measuring method is omitted and measured results alone are given here because the measuring method is described in the literature by Koike et al. (1990) and Sugawara et al. (1991). Table 2 shows the sensitivity calibration value of each FM measured at Kakioka using the large Helmholtz coil. As is obvious from Table 2, the sensitivity calibration value is very close to 1.000 for each FM, and these are the results of measurement performed after calibration by the manufacturer.

As a conventional means of monitoring the FM sensitivity, a constant magnetic field is created by the built-in reference power source of the FM and the calibration value is found from that output value. There has been no way other than this so-called built-in sensitivity measurement and no method available to ascertain whether the sensitivity calibration value obtained in this way is reliable or not. This is because the calibrating magnetic field is created inside the sensor by the built-in constant voltage power source of the FM. Therefore, if the measured sensitivity calibration value changes with time, it is impossible to know whether that change is due to the variations in time of the output of the constant voltage power source or due to the true change in time of the

Table 2 Result of the measurements of the DC-sensitivity of the three FMs. The measurements were carried out in ± 500nT.

	H	D	Z
96FM (MMB)	1.0004	0.9996	0.9997
90FM (KAK)	1.0001	0.9994	1.0005
95FM (KNY)	0.9995	0.9999	0.9997

calibration value. Thus, the high sensitivity FM was improved by changing its configuration to enable the calibration voltage to be impressed from the outside and this made it possible to monitor the impressed voltage value. It also became possible to use a voltage source with high accuracy according to the required calibration accuracy. The calibration voltage may vary with time, causing an error in the sensitivity calibration value, but this error can be eliminated in this way.

Table 3 shows the computed intensity of the magnetic field impressed on the sensor core with a voltage of 1 V impressed as the external calibration signal. After this, this value will be used for long-term confirmation of sensitivity calibration values for each FM.

Nevertheless, there is no assurance that a constant of the external sensitivity signal itself will never vary with time after this. This is because the externally impressed voltage is converted by the V/I converter in the FM itself into a current, which in turn creates the sensitivity calibration magnetic field. That is, if a constant of the V/I converter varies with time, an apparent variation may occur in the measured calibration value. The improvement this time could eliminate one of the large uncertainties in sensitivity measurement, but other uncertainties still remain. In the future as well, it will be necessary to measure the constants of the external sensitivity signal again to keep track of the variations, and this will be done as the need arises.

2-2-2. AC sensitivity

The measurement was performed for each analog output (DC to 5 Hz filtered or DC to 1 Hz filtered) of the two lines of the FM. To create the alternating magnetic field, an alternating current was made to flow through the large Helmholtz coil. The frequencies used for the measurement were 16 periods from 0.001 to 5 Hz. For 0.001 to 0.1 Hz, 10-Hz samplings were recorded and processed and for higher frequencies, 100-Hz sampling was used.

Figure 1 shows an example of the H-component of sensitivity measurements using the large Helmholtz coil. Similar results were obtained for the other components. In Figure 1, every FM has flat sensitivity characteristics in the frequency region of 1 Hz or less. At higher frequencies, the sensitivity calibration value gradually increases (the gain decreases). The phase angle is almost 0 degrees at 0.1 Hz or less, but it decreases at higher frequencies (the phase of the output value lags behind the variations of the external magnetic field). This result is close to the result derived by Yamamoto and Koike (1996) for the MB 162 type FM, and it seems that intrinsically, the same type of filter was used.

2-3. Orthogonality measurement of 3 axes

The deviation of the angle between the FM axes was measured from 90 degrees at Kakioka, and Table 4 shows a summary of the measurements for each FM. An error in orthogonality reduces the measurement accuracy of measured

Table 3 Intensity of the magnetic field produced within the sensor when an external calibration signal of 1 volt is applied (nT/V).

	H	D	Z
96FM (MMB)	104.28	104.33	104.03
90FM (KAK)	110.91	110.76	110.71
95FM (KNY)	110.79	111.02	110.97

Table 4 Result of the measurements of the angle within the three axes of the sensor for the three FMs. Numbers indicate deviation from the rect-angle. All were measured in the field of 500 nT.

	∠HD	∠HZ	∠DZ
96FM (MMB)	−4′12″	+2′03″	−2′12″
90FM (KAK)	+2′05″	+4′10″	+2′58″
95FM (KNY)	+1′01″	−3′23″	+2′06″

component values, but this is inevitable due to the machining accuracy of the sensor core block.

2-4. Noise level measurement

Measurements of the 96FM were performed and the results are shown in Figure 2. In the measurement, the sensor is placed on the west pillar in the absolute house, and the analog signals after passing through a filter of DC to 5 Hz were recorded directly on a pen recorder component by component. The 3 components are depicted in one figure for the sake of convenience, but this does not mean that they are recorded at the same time. For each component, the noise width is about 0.02 nTp-p, which satisfies the specifications given in Table 1. This is a little larger than the 90FM, which had 0.01-odd nTp-p (Tsunomura et al., 1994). This value contains short period noises

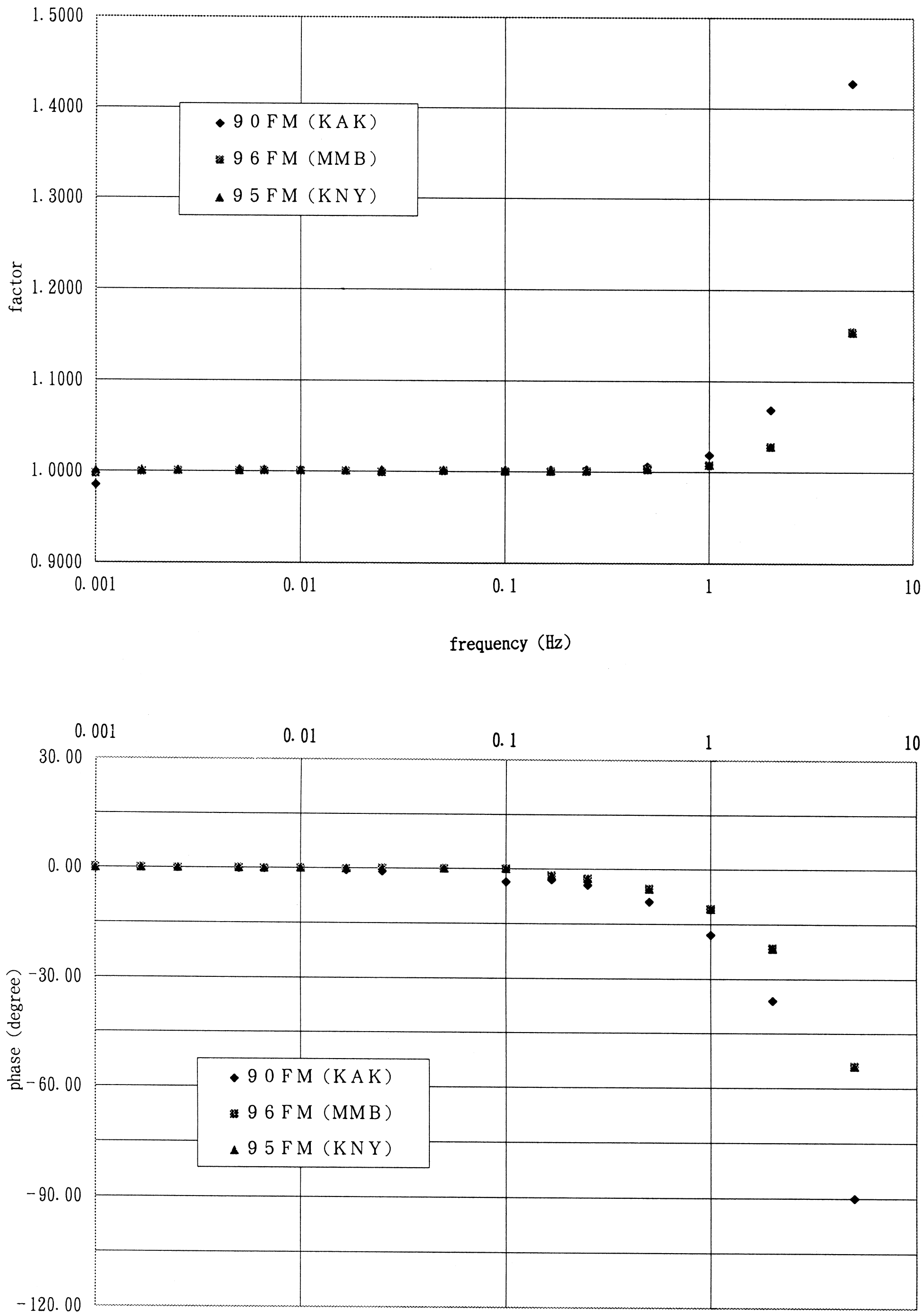

Fig. 1 Sensitivity of the three FMs (H-component) against the frequency from 0.001 to 5Hz measured by use of a large Helmholts Coil system.
upper: amplitude factor, lower: phase

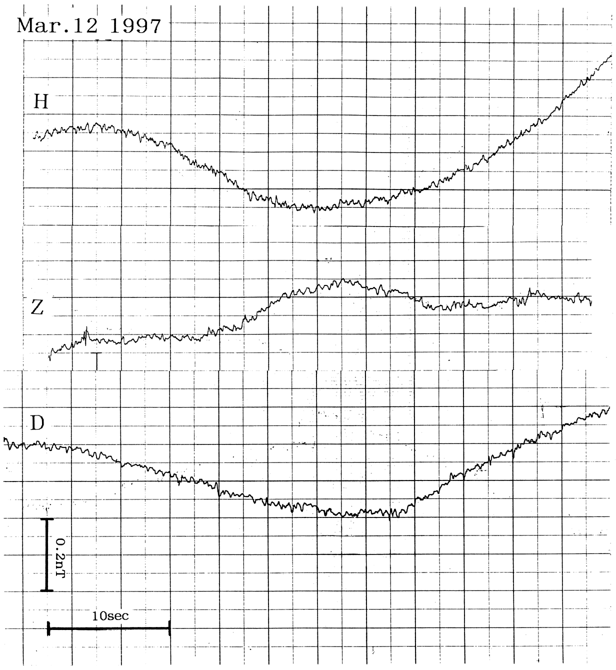

Fig. 2 Noise-level of 96FM for the three components.

because the measurement was performed in the daytime when artificial noises were abundant.

3. Measurement control, processing and analysis section

The measurement control, processing and analysis section consists of a signal splitting unit, serial data converter and other devices made anew this time, a data monitor on the market, a data processor, personal computers (abbreviated to PCs hereafter) used with analyzers, peripheral equipment and data recorders. The PCs are connected to one another by a LAN to minimize the use of media in data exchange. The data to be obtained are 1-second and 0.1-second values.

An adequate time accuracy is required for the timing to measure the FM and record the 1-second and 0.1-second values. Therefore, a clock device was employed that could receive the JJY signal and automatically calibrate itself.

When developing the measurement control, processing and analysis section, it was designed considering the following:

(1) Reliability:

Must be able to record the geomagnetic variations by 0.1-second and 1-second sampling for 24 hours a day without missing.

(2) Operability:

Must be able to be operated easily because it is operated as routine work.

(3) Flexibility:

The components of the equipment must be separable into blocks if a portion of it fails, so that the least minimum part can be separated with the remaining part conducting data recording.

The data recording section is made in a duplicate configuration to avoid missing observations due to a failure of the recorders.

3-1. Hardware configuration and major functions

In configuration, the hardware consists of the following instruments (Figure 3 for both Memambetsu and Kanoya and Figure 4 for Kakioka):

a. Signal splitting unit

It receives digital and analog signals from the FM, proton magnetometers and other various observation instruments, and splits them. The split output signals are protected so that one output signal will never affect the other output even if it makes a short circuit. The following signals are split.

(1) Second pulse

It receives 1-second pulses from the clock device and splits them into 5 signals, which are used as the measurement trigger for the FM and data recording trigger for the 10-Hz signal generator and serial data converter for 0.1-second measurement.

(2) Analog signal

Analog signals on 15 channels can be entered. All signals are split into 3 lines and delivered to the 3 serial data converters. Three of the 15 channels are used for the input of analog signals from the inclinometers (2 channels in the east-west and north-south directions) and thermometer (1 channel) mounted inside the FM sensor. The other 12 channels can be used as standby.

(3) BCD signal

It receives digital BCD signals from the two vector proton magnetometers (F, H), splits each of them into 3 lines and delivers them to the 3 serial data converters.

(4) Clock information

It receives digital BCD of 12 digits from the clock information (the 2 lowest significant digits of the year, and 2 digits each for the month, day,

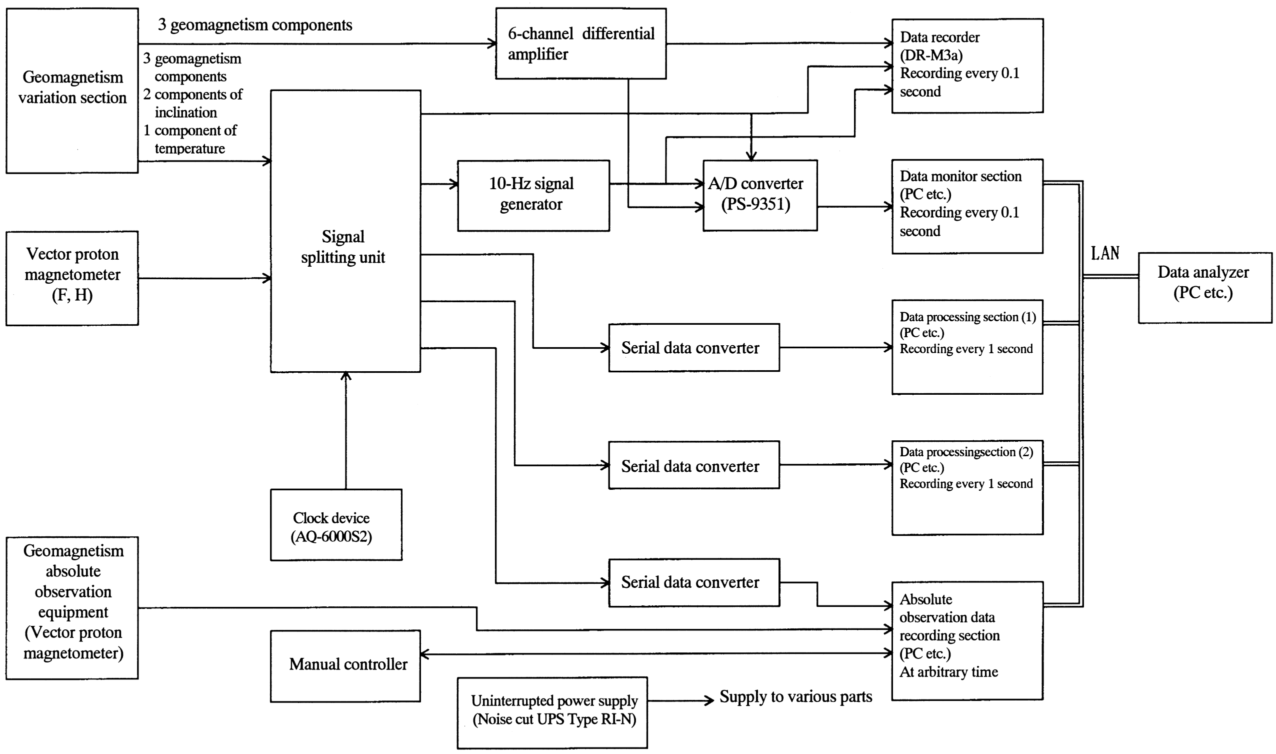

Fig. 3 Block diagram of the constitution of the measurement-controlling, data transforming and ending unit of the system at Memambetsu and Kanoya.

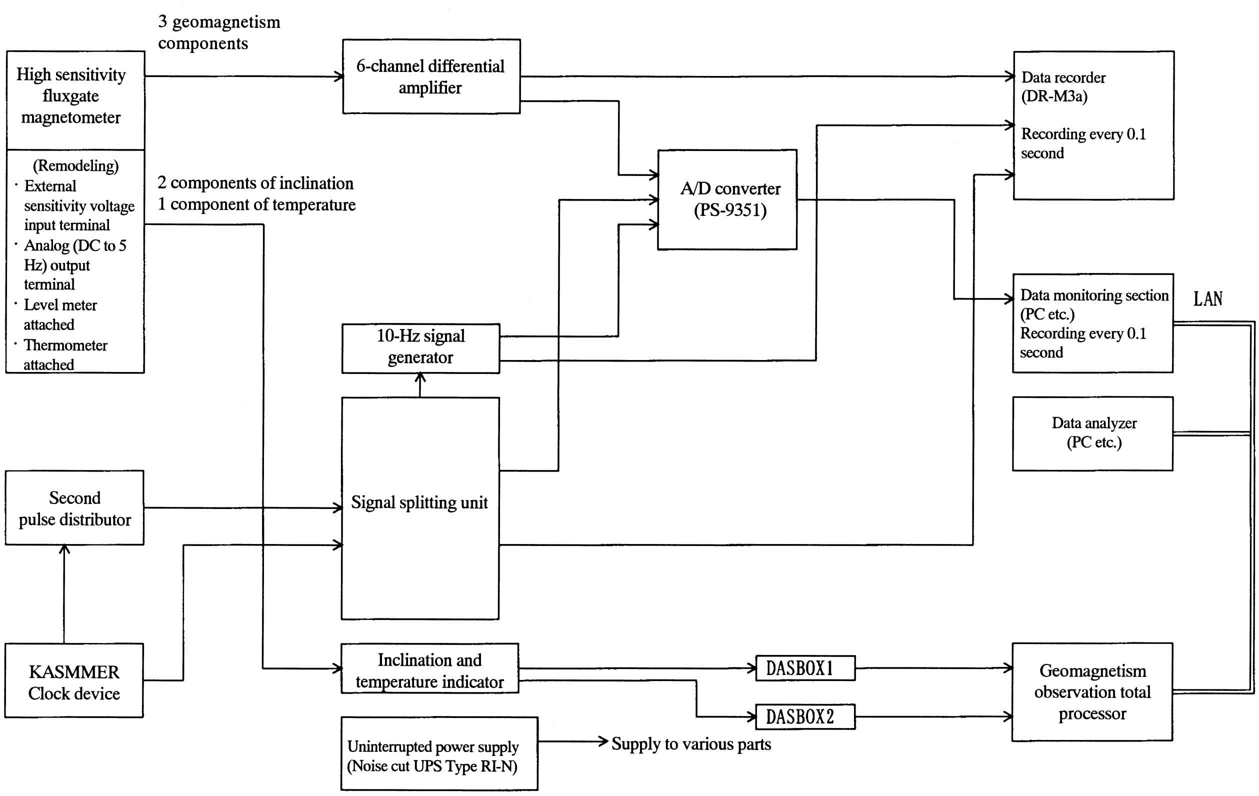

Fig. 4 Block diagram of the constitution of the measurement-controlling, data transforming and ending unit of the system at Kakioka.

hour, minute and second) delivered by the clock device, splits the signal into 3 lines and delivers them to the 3 serial data converters. In addition, it delivers 16 bits of clock information (to the data recorder DR-M3a), 2 bits of clock information (to the A/D converter PS-9351) and 1 bit of time mark (hour).

(5) RS-232C signal

It receives measured values delivered as the RS-232C signal from the FM amplifier, splits them into 3 lines and delivers them to the 3 serial data converters.

b. Serial data converter

Conducts data conversion and buffering for delivering the data to data processing sections 1 and 2 and the absolute observation data recorder. Three pieces of the same type are used. The data is processed in the following order.

(1) A/D conversion

Conducts A/D conversion (successive conversion type with a resolution of 16 bits) of the analog data entered from the splitter circuit in sync with the 1-second pulse signal entered from the splitter circuit. For each channel, A/D conversion is repeated 100 times for 0.5 seconds and the arithmetic mean is delivered. The input range can be switched over between ± 5 V and ± 10 V.

(2) Data conversion

Converts the data after A/D conversion and all the data entered as digital data from the splitter circuit into ASCII character strings.

(3) Buffering

Buffers the data after ASCII conversion and delivers it through RC-232C according to the transfer request from the recorder. When delivering data to the absolute observation data recorder (at Memambetsu), it must always be real-time data without being buffered. Therefore, the buffer function is made switchable between enable and disable. The buffer capacity is 1 megabyte.

c. 6-channel differential amplifier

It receives the analog signal of 3 components (H, Z, D) from the FM amplifier, removes the noise and long-period components by an HPF (high pass filter) and LPF (low pass filter), and amplifies the signal. After amplification, the signal is sent to the data recorder DR-M3a and the A/D converter PS-9351.

(1) Filtering

Pulsating phenomena, Pc and Pi, were observed. Their periods extended from 0.2 seconds (Pc 1) to 600 seconds or more (Pc 6). The HPF was made to have a cut-off frequency of 150 seconds and cut-off characteristics of −60 dB or more at 1000 seconds. This is to keep track of the phenomena of Pc 1 through Pc 4 (0.2 to 150 seconds). As a measure to counter high frequency noises on commercial power and so forth, an LPF with cut-off characteristics of -60 dB or more was set at 50 Hz. Figure 5 shows the frequency characteristics of the 6-channel differential amplifier at Kakioka.

(2) Amplification

The amplification factor is switchable among 0.1, 1, 5, 10 and 100 so that matching of the intensity of input signals can be attained. For each channel, the number of outputs is 3.

d. A/D converter PS-9351

It receives analog data from the 6-channel differential amplifier and conducts A/D conversion on it in sync with the 0.1-second pulses entered from the 10-Hz signal generator. The A/D conversion is of the successive approximation type with 14-bit resolution and can support 32 channels. The least significant one bit of the “hour” value and “minute” value are each entered in digital form and they are delivered with the A/D converted data. This converter is provided with an output buffer of 30 kilobytes. The input range can be switched over between ± 2 and ± 5 V. The output is delivered to the data monitor section in the form of a GP-IB signal. This converter is commercially available (from TEAC Co., Ltd).

e. 10-Hz signal generator

It receives 1-Hz pulses from the signal splitting unit, multiplies them by 10 and feeds them to the A/D converter PS-9351 and data recorder DR-M3a as a sampling clock for 0.1-second value sampling.

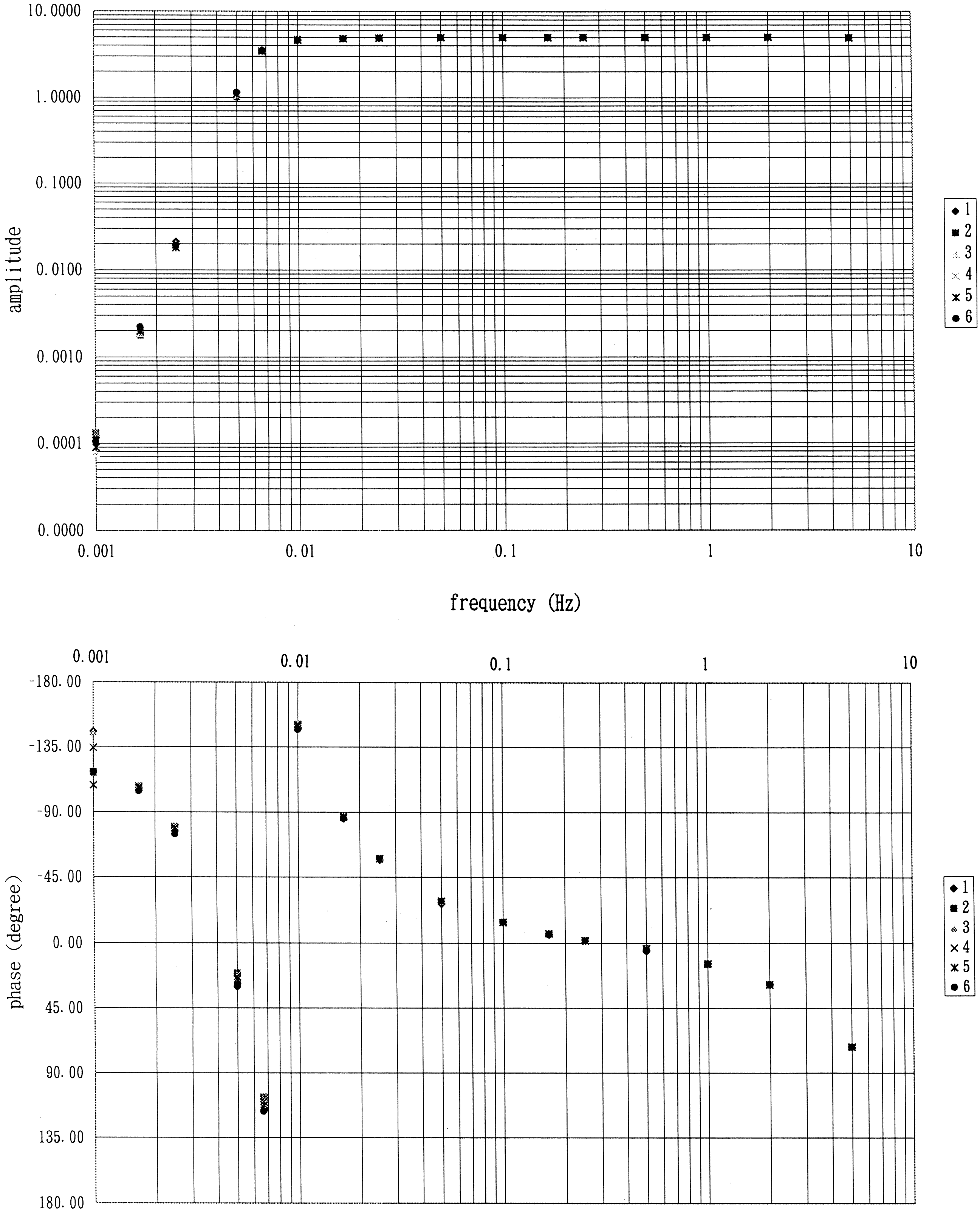

Fig. 5 Frequency-dependence of the output of the 6ch-amplifier at Kakioka. upper: amplitude factor, lower: phase.

f. Data recorder DR-M3a

The data recording section consists of the commercially available DR-M3a (made by TEAC Co., Ltd). This device receives analog signals from the 6-channel differential amplifier, conducts A/D conversion and records the converted signals every 0.1 seconds. It writes them on a 3.5-inch magneto optical disc together with the 16-bit clock information entered from the signal splitting unit. The supported magneto optical discs are of double and single densities (230 and 128 megabytes), which are automatically switched over. A/D conversion takes place with 16-bit resolution. This recorder supports input on 8 channels and simultaneous sampling of all channels. The input range can be selected from among ± 1, ± 2, ± 5 and ± 10 volts.

g. Data monitor section

A PC made by NEC was employed for the data monitor section. For observing geomagnetic pulsations, data are delivered from the data converter every 0.1 seconds. This computer records the 0.1-second data together with the clock information. It displays the time-series graph and numerical list of a certain length of past time, including the latest data, on the display. The OS is Windows 95.

h. Data processing sections 1 and 2

A PC was employed for the data processing sections. It receives the 3 geomagnetism components from the serial data converter and the inclination data, temperature data and clock information from the FM sensor and records them every second without missing. It also has the capability to display the latest recorded data in real time and in numerical and graphical representation. In the data processing sections, 2 sets of equipment with the very same function are provided and recording takes place concurrently to avoid missing observations due to a PC failure.

i. Data analyzer

The data analyzer edits and analyzes the 0.1-second and 1-second values obtained by the data monitor section and data processing sections, and processes the regularly reported values and others. It consists of a PC, a page printer and other peripheral devices. This analyzer is connected by a LAN to the data monitor section, data processing sections 1 and 2 (and the absolute observation data recording section at Memambetsu only).

j. Absolute observation data recording section (at Memambetsu only)

Conventional absolute observation requires 3 persons: an observer to operate the magnetic theodolite, a recorder to enter the measured values in the field note and a controller to measure the total magnetic force by a proton magnetometer and check for abnormal values in the intervals between measurements. The processing of measured values also has to be performed manually in many parts. As a labor-saving method, an absolute observation data recording section was prepared consisting of a PC and manual controller. By operating the absolute observation data recording section, the human recorder can take in FM data and control the proton magnetometer, and take in its data. It is also possible to determine whether the observation is good or bad during observation.

k. Clock device AQ-6000S2

Clock information with high accuracy is required to do sampling every 0.1 seconds for observing pulsations. Thus, a clock device (AQ-6000S2 made by ECHO KEISOKUKI Co., Ltd.) was employed capable of receiving the JJY signal (10 MHz in the short-wave band) and calibrating the time automatically. The major specifications are given below.

Overall time accuracy	±5 msec (if corrected at 6-hour intervals)
Automatic calibration range	Within ± 0.5 sec.
Time correction accuracy	Within ± 2.5 msec.
Quartz oscillator	1 MHz $\pm 5 10^{-8}$ per day (placed in a thermostatic oven)

l. Uninterrupted power supply, noise cut UPS Type RI-N

The employed uninterrupted power supply (Noise cut UPS Type RI-N made by Denkenseiki Research Institute Co., Ltd.) has a built-in noise cut transformer to block noises on the power line or those emitted from the equipment.

3-2. Programs

3-2-1. Data files

There are several types of data files. Table 5 shows the symbols and types of data files. In the table, the symbol following / in the file size indicates the unit of file creation. For example, / hour indicates that a separate file is created every 1 hour.

od and os indicate the recorded original data files of 0.1-second and 1-second values, which go through format conversion and data correction to become the final data files. d3 indicates the newly added final 3-component file of 0.1-second values and its format is shown in Table 6.

s1 and m1 are the data files of one-component 1-second and 1-minute values, respectively. Temperature and inclination data are filed in the s1 and m1 formats. This file contains information to convert the data into physical quantities. s4 and m4 are 4-component 1-second and 1-minute values, respectively.

3-2-2. Data flow

The recorded data and their processing are broadly divided into 0.1-second values (change rate observation data) and 1-second values (change observation data). Therefore, the programs are also divided into programs for 0.1-second values, for 1-second values and for 1-minute values. The data are processed in a straightforward order, as follows:

Change rate observation data od → d3
Change observation data os → s4 → m4
(provisional value)→ m4 (final value)
→ 1-hour value
Temperature and other data os → s1 → m1

4. Measured data sample

The data obtained by the geomagnetic change observing equipment are shown. Figure 6 plots the 0.1-second values of Pi 2 starting at 11:59 on October 19, 1997 (UTC) at Memambetsu, Kakioka and Kanoya. Figure 7 shows the output of 1-second values of the H-component at Memambetsu, Kakioka and Kanoya during the magnetic storm (ssc) that began at 09: 49 on November 22, 1997 (UTC). Observing these 0.1-second and 1-second values, short-period phenomena can be detected more clearly than conventional analog recording by an inductive magnetometer and suspended magnet variometer. This is expected to be widely used for research in various fields.

The final digital values are gathered at Kakioka and saved on a magneto optical disc as well as being offered to the World Data Center every month.

5. Conclusion

During the two years from 1995 to 1996, the geomagnetism change observation equipment was renewed at both Memambetsu and Kanoya Magnetic Observatories, the 90FM was remodeled and the observing equipment improved at Kakioka. It became possible to observe the geomagnetism as digital data of 0.1-second and 1-second values with high accuracy. To maintain the high accuracy of observation, however, the following questions remain.

(1) A function was added to the sensor to impress a sensitivity calibration magnetic field by an external voltage source. Voltage-to-current conversion takes place in the FM itself, but will this converter circuit never vary with time?

(2) How high is the long-term stability of the

Table 5 List of data-file.

Symbol	Type	Number of components	File size
od	0.1-second value	1-6	432 Kbytes/hour (6 components)
d3	0.1-second value	3	5.898 Mbytes/day
os	1-second value	1	346 Kbytes/day
s1	1-second value	1	5.714 Mbytes/month
s4	1-second value	4	22.856 Mbytes/month
m1	1-minute value	1	95 Kbytes/month
m4	1-minute value	4	381 Kbytes/month

Table 6 Record-format of 0.1-second value file (d3).
X': Magnetic North, Y': Magnetic West, Z: Downward
1-record:1024-byte (data of 3 components for 15 seconds)

Word	Byte	Type	Content
1	2	Integer	Year (1997, 1998, ...)
2	2	Integer	Month (1, 2, 3, ..., 12)
3	2	Integer	Day (1, 2, 3, ..., 31)
4	2	Integer	Hour (0, 1, 2, ..., 23)
5	2	Integer	Minute (0, 1, 2, ..., 59)
6	2	Integer	s (first second of interval (0, 15, 30, 45))
7	2	Integer	Accumulated days (1, 2, ..., 366)
8	2	Integer	Accumulated minutes (1, 2, ..., 1440)
9	2	Integer	First second of accumulated intervals (1, 16, 31, ..., 3585)
10	2	Integer	Information code
11	2	Integer	Number of digits of constant value of X'-component
12	2	Integer	Resolution of variation of X'-component
13	2	Integer	Constant value of X'-component in interval from s to s+4.9 seconds
14	2	Integer	Constant value of X'-component in interval from s+5.0 to s+9.9 seconds
15	2	Integer	Constant value of X'-component in interval from s+10.0 to s+14.9 seconds
16	2	Integer	Variation of X'-component at 0.0 seconds
17	2	Integer	Variation of X'-component at 0.1 seconds
•	•	•	
•	•	•	
165	2	Integer	Variation of X'-component at 14.9 seconds
166	2	Integer	Number of digits of constant value of Y'-component
167	2	Integer	Resolution of variation of Y'-component
168	2	Integer	Constant value of Y'-component in interval from s to s+4.9 seconds
169	2	Integer	Constant value of Y'-component in interval from s+5.0 to s+9.9 seconds
170	2	Integer	Constant value of Y'-component in interval from s+10.0 to s+14.9 seconds
171	2	Integer	Variation of Y'-component at 0.0 seconds
172	2	Integer	Variation of Y'-component at 0.1 seconds
•	•	•	
•	•	•	
320	2	Integer	Variation of Y'-component at 14.9 seconds
321	2	Integer	Number of digits of constant value of Z-component
322	2	Integer	Resolution of variation of Z-component
323	2	Integer	Constant value of Z-component in interval from s to s+4.9 seconds
324	2	Integer	Constant value of Z-component in interval from s+5.0 to s+9.9 seconds
325	2	Integer	Constant value of Z-component in interval from s+10.0 to s+14.9 seconds
326	2	Integer	Variation of Z-component at 0.0 seconds
327	2	Integer	Variation of Z-component at 0.1 seconds
•	•	•	
•	•	•	
475	2	Integer	Variation of Z-component at 14.9 seconds
476	74		Empty area
•	•	•	
•	•	•	
512			

FM measured value?

(3) The data recording and related section is based on PC, but how high are its durability and reliability?

To answer these questions, it will be necessary to continue the study and improvement.

Finally, the new equipment has improved the accuracy and resolution of data at geomagnetic observatories including Kakioka, Memambetsu and Kanoya Magnetic Observatories to an unprecedented high level. Because the data are digitized, they can be used in various fields. Notwithstand-

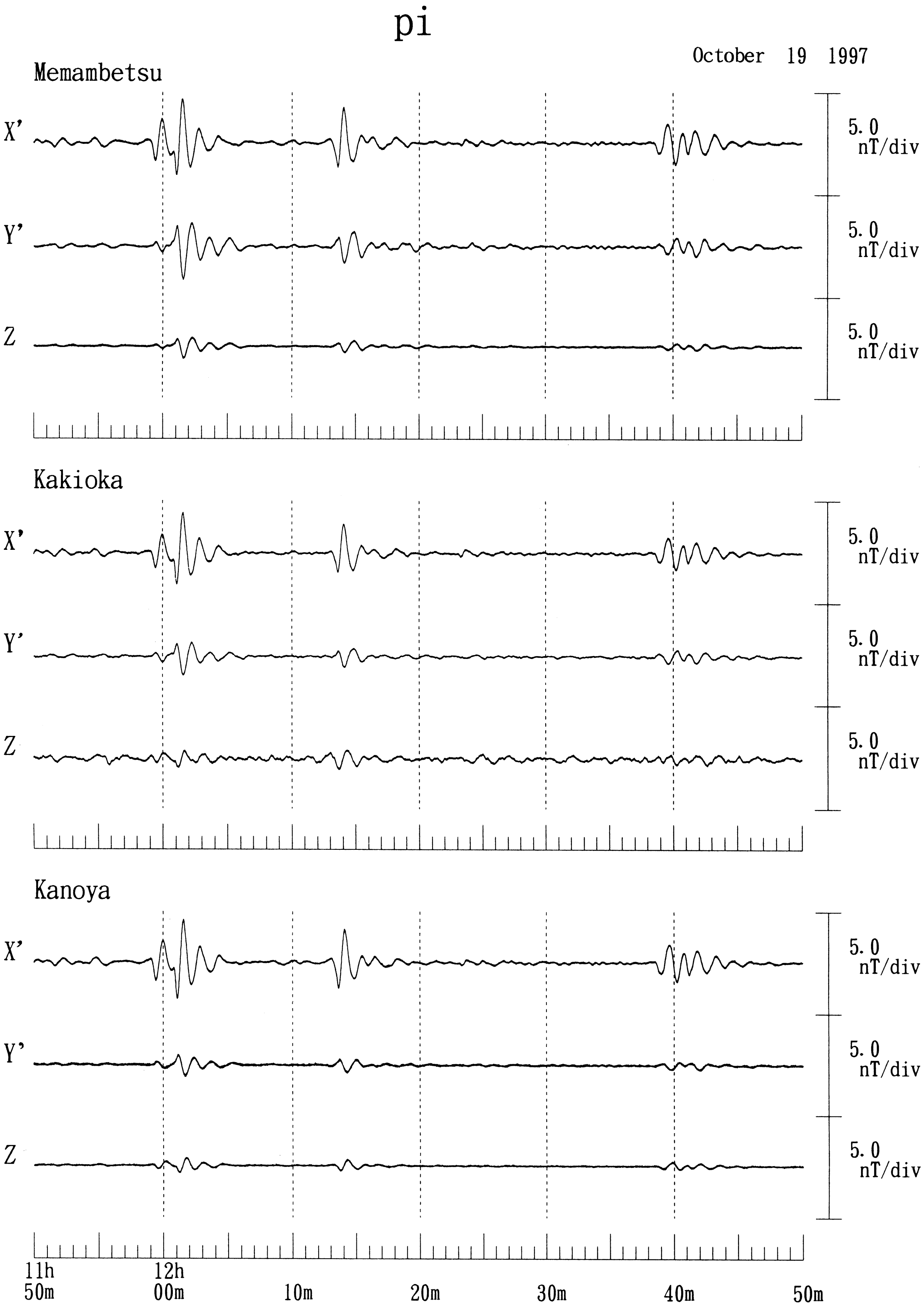

Fig. 6 Example of a plot of 0.1-second values showing a Pi pulsation at Memambetsu, Kakioka and Kanoya. X': magnetic northward, Y': magnetic westward, Z: downward

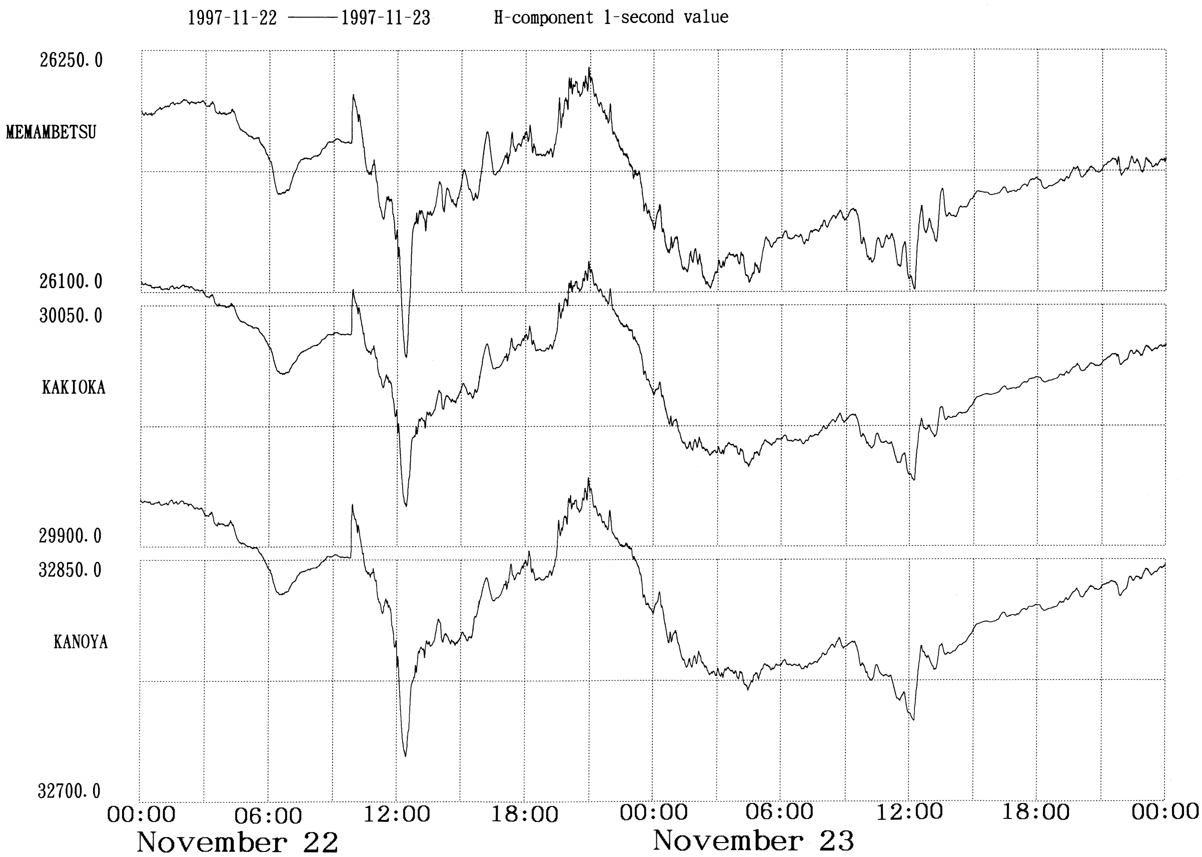

Fig. 7 Example of a plot of 1-second values at Memambetsu, Kakioka. and Kanoya for the H-component.

ing in-house use, much use is expected from related institutions.

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