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The New System of Kakioka Automatic Standard Magnetometer

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Abstract

The part of variation measurement of Kakioka Automatic Standard Magnetometer (KASMMER) was replaced as a four year program from 1989 to 1992. The new instrument is a set of a high sensitivity fluxgate magnetometer and four Overhauser magnetometers with three Fanselau-Braunbek Coils. The former is for getting high resolution one second values and the latter for stable base lines. After test observations for about one year, the sensors of optical pumping magnetometers which have been used these 20 years were replaced with those of Overhauser magnetometers and the routine observation by the new instrument was started at April, 1993. The computer system which had been two sets of stand-alone mini computers was also replaced with the new system composed of seven UNIX work stations connected by ethernet cables. In this article, we introduce the design of the new system of KASMMER and report the brief observational results.

1. Introduction

In Kakioka Magnetic Observatory, the variation observation of geomagnetic field has been quite stably continued using optical pumping magnetometers these two decades (Kuwashiama (1990a)). The optical pumping magnetometers have kept the good conditions same as the initial state (Sano (1975)) and highly reliable one minute values have been obtained after the quality check and correction of original one minute values which were the averages of one second values from 30 second to 29 second. The magnetometers had the capability of 0.01 nT resolution for one second values, however the high resolution observations have not been operated because of the limitation of capacity of mini computer system.

After long term continuous observation, the instrument has become old resulting in low S / N ratio and frequent irregularity of temperature controllers. The committee for the replacement project of KASMMER was held several times in our observatory and it was decided to replace the optical pumping magnetometers which have been taking share of precision (or resolution) (Green (1990)) in KASMMER. DI72 and a proton magnetometer used for absolute measurement were decided to be maintained (Tezuka (1990)).

Before the designing the new variation instrument, requirements for the specifications of the instrument were reviewed. There may be new needs but, on the other hand, the overspecification should be avoided although the previous one had splendid performances. The matters to be reviewed are the sampling rate, resolution of measurement and stability of observation.

One second values have been recorded continuously since 1983. It has been growing the scientific needs for high time sampling data in recent years. The data are used in pulsation analysis, CA, MT and other analyses by scientific users (e.g. Green et al. (1993), Saka and Alperovich (1993), Tsunomura et al. (1990), Yumoto et al. (1993)). High time sampling data are also useful for routine works such as to trace the rapid geomagnetic variations (e.g. SSC's or SI's) and/or pulsation detections. It was decided beyond controversy to continue the recording of one second values by the committee. It was not regarded practical to record data by higher sampling rate than one second for the continuous data recording.

Resolution of measurements of one second values was desired to be upgraded from the previous value of 0.1 nT by many scientific users. Since the sensitivity response is almost flat with frequencies, one second values of optical pumping or fluxgate magnetometers are easier to use than those of induction magnetometers. As a matter of fact, fluxgate magnetometers have been used in high sensitivity measurements for various scientific purposes, (e.g. Saka and Alperovich (1993), Yumoto et al (1992)) instead of induction magnetometers. Considering the usual amplitudes of geomagnetic pulsations of Pi 1, 1, 2 or Pc 2～5 ranges, it is estimated that the resolution of 0.01 nT is preferable and sufficient (Fig. 1). The value is not thought as an unreasonable objective for optical pumping or fluxgate magnetometers. It was decided that the measurement resolution and the recording unit of digital data of one second values are upgraded to 0.01 nT.

The base line stability is an important matter. Base lines of optical pumping magnetometers in recent yeas are shown in Fig. 2 (C-Values are equivalent to base lines except that the signs are opposite.) The C-values of F and H components have been obtained quite stably (excluding the fluctuations of C-value of H component caused by rain falls) and those of Z and D components have been within the stability of ～ ±1 nT. The base line stability contributes to the accurate derivation of Dst index or other matters required for the standard magnetic observatory. The needs for stability has been growing for the reference of the field work such as volcanic observations which have been developed very much in recent years. For example, a few nT variation associated with volcanic activity is discussed for the magnetic observation at Unzen volcano in Japan (Churei et al. (1992)).

The base line stability of observatories are, therefore, required to continue the present value as long as possible. However, the base line stability can not be described explicitly in the technical specification of the new instrument to purchase. The stability is nothing less

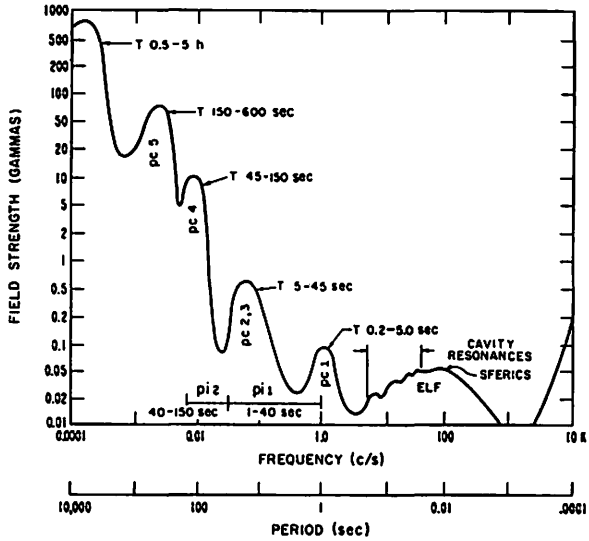

Fig. 1 Identification of geomagnetic pulsation spectrum in the lower frequencies (after Campbell (1966)).

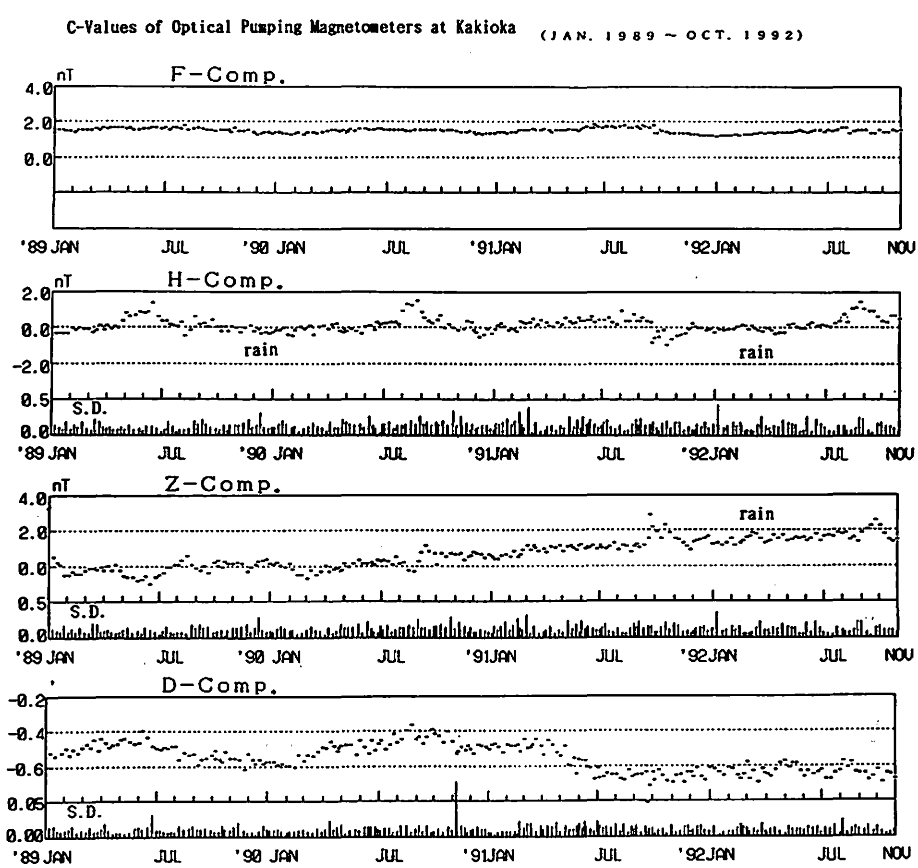

Fig. 2 C-values of optical pumping magnetometers (1989 Jan. — 1992 Oct.) obtained by the routine observation.

than the observational result.

These requirements may be satisfied altogether if the optical pumping magnetometers are used. However, it is expected to be enough that the resolution of measurements and the stability are satisfied independently by two magnetometers. Indeed, a set of a fluxgate and proton precession magnetometers is thought to satisfy the above requirements totally.

As the sensor houses of the optical pumping magnetometers are to be used, the mutual influences of the magnetic fields produced by the driving current would become a problem if the traditional type proton precession magnetometers were adopted. To avoid the mutual interferences, the measurement system may have to be rather complicated to synchronize the timings of driving currents exactly.

As the IAGA resolution (No. 12 of 1979 Meeting at Camberra) recommended as a guide-line that one minute values would be derived based on the data sampled higher than or equal to ten seconds, it is preferable to take the data by high sampling rate of 10 second or less. It was thought that Overhauser magnetmeters can get easier the sufficient measurement resolution without heating the sensors than the traditional type proton precession magnetometers under high sampling rate. As to the measurement stability, Overhauser magnetometer is expected to be comparable with the traditional proton precesion magnetometer.

Overhauser magnetometer was thus thought to be the better choice for the set of two types of magnetometers. A brief test observation before the construction of the new magnetometers showed good observational result of geomagnetic total intensity by GSM-11 Overhauser magnetometer comparing with KASMMER.

The committee decided that the optical pumping magnetometers and the set of fluxgate and Overhauer magnetometers are equivalent in realizing the requirements for data quality.

The technique to make optical pumping magnetometers have not been persisted by the manufacturer of the prievious optical pumping magnetometers. Another Corporation who can afford to manufacture optical pumping magnetometers have not sufficiently experienced the ground observations and claimed that they would need much cost to develope the project of newly designed Helium optical pumping magnetometers for the ground observation. It was estimated that the cost was more than six times larger than that for the set of fluxgate and Overhauser magnetometers.

Under these situations, it was finally decided to adopt the set of a fluxgate and four Overhauser magnetometers for the new variation instrument. In 1989, a fluxgate magnetometer was installed and from 1990 to 1991, Overhauser magnetometers and Fanselau-Braunbek coils were purchased. The designs of these magnetometers will be introduced in the next section.

Together with the replacement of the variation instrument, the computer system was also replaced. The computer system has been replaced twice since the start of the KASMMER system at 1972, but the basic architecture of the system has not been changed. There have been two sets of mini computers of Hitachi Corp. controled by their own operating system without any compatibility with other computers. They are not connected by communication lines each other. However, the mini computers are the unique choice in the past for the system which can satisfy the following reqirements altogethr; heavy duty for long term continuous data recording, safety of data acquisition on the multitask operating system, capabilitiy to support various peripherals such as 1/2 inch magnetic tape drive, XY plotter, graphic display and line printer and so on, capability to submit the batch process through telecommunication line to the main frame computer system of Meteorological Research Institute via RJE. We have been using the system for scientific calculations or data exchange also.

Recent development of capabilities of personal computers and / or work stations enables us to extend the branches of selections. It was thought that adopting the computers driven by the standard operating system may contribute to decreasing of the cost for ordering the routine software of data processing, increasing ability for scientific use such as making complicated graphics, data exchange through the communication lines and other various matters. Small computers can contribute to make the data acquisition part compact also.

Considering the total efficiencies for the above requirements, it was decided to adopt a system which consists of work stations connected by ethernet cables. The synoptic description about the new computer system will be given in the section 3.

2. The new variation instrument

2.1 High sensitivity fluxgate magnetometer

Because of the portability and simplicity of maintainance, fluxgate magnetometers have been extensively used in many observatories (e.g. Stuart (1990), Wilson (1990)) and the satellite observations (e.g. Acuna et al. (1978), Fukunishi et al. (1990)). Fluxgate magnetometers with ring core sensors can attain high sensitivity and low noise level less than 0.03 nT (e.g. Saito et al. (1983)). It is reported that some of the ring core sensors show noise levels less than 0.01 nT at 1 Hz (Narod and Bennest (1990), Shimoizumi et al. (1991)).

Biaxial fluxgate magnetometers have been also showing good results for both of sensitivity and stability (Koike et al. (1990), Kuwashima (1990b)). In our observatory, biaxial type fluxgate magnetometers, MB160 and / or MB162 of Shimadzu Corp. have been used at Kakioka, branch offices at Memambetsu and Kanoya, Chichijima unmanned station and various field observations and it is recognized that they can yield stable base lines (Kuwashima (1990b)). The noise level of MB162 is evaluated less than 0.05 nT from the actual observations.

One of our objectives to attain the measurement resolution of 0.01 nT was expected to be realizable by both of ring core and biaxial sensors. The high sensitivity and low noise level are basically obtained by making the sensor core long to increase the dimention ratio, that is the ratio of the length of the core to the effecvtive thickness of it. The ring core sensor may be able to increase the sensitivity easier than biaxial one, but the temperature dependence of the ring core sensor would not be so good unless the surrounding coils can make sufficiently large uniform zones of magnetic fields around the core. Solenoid coils may satisfy such requirement but is thought to be hard to get the sensitivity. The biaxial type has the advantage for getting the stability of measurement compared with ring core type.

Although the main role of fluxgate magnetometer is to get high resolution, the measurement status should be kept stable so long as the required resolution is attained. We decided to make the new fluxgate magnetometer by biaxial core architecture. We ordered to manufacture the fluxgate magnetometer to Shimadzu Corp. After examinig the test results of several samples reported by Shimadzu Corp., we adopted one of the cores with the length longer than those of MB160 and / or MB162. An example of the analogue records of test observation is shown in Fig. 3. It can be seen that the noise level of short period (less than several seconds) is nearly equal to 0.01 nT.

The synopses of the sensor and the amplifier are shown in Fig. 4 and a sketch of the sensor and a block diagram of measuring system in Fig. 5 and Fig. 6, the basic characteristics of the magnetometer in Table 1, respectively. The analogue signal is devided to an attenuator giving auxiliary output of 10 mV range which is transmitted to DCP of INTERMAGNET now.

Digital signal is produced by 17 bit (16 bit data and 1 bit sign), triple slope integrating A / D converter (MP 8037 of ANALOGIC) and has a resolution of 0.01 nT with the dynamic range of ±500 nT. The timing chart of A / D conversion and data output is shown in Fig. 7. A / D conversion starts just after the external trigger and 32 times conversions are performed for each component. Each conversion needs 6 ms. After the completion of the A / D conversion, the data are averaged and put out. The averaging period is 576 ms from the external trigger. This is a little smaller than that of the previous optical pumping magnetometers, the counting gate of which were about 714 ms, but may not cause a severe difference.

The sensitivity was calibrated using three axes large square Helmholtz coils constructed at the start of KASMMER (Yanagihara et al. (1973)). The method and the accuracy of calibration by the Helmholtz coils is discussed by Koike et el. (1990). In the routine observation, the internal sensitiviy calibrator is used once a month to check the long term variation of sensitivity.

A sensor house with a cellar of 5.3 m depth was constructed to install the sensor. The basic design of the sensor house is same as the step parts of those of Memambetsu and Kanoya branch offices. The sensor house is made of non-magnetized resin concrete. The synoptic design of it is shown in Fig. 8. The variation of base lines of the fluxgate magnetometer and the temperature in the cellar are shown in Fig. 9. The annual ranges of the temperature of the cellar is larger than expected, resulting in the annual variations of the base lines with the ranges of nearly several nT. The temperature variation would be decreased (maybe 2~3℃/ year) by covering the sensor house with soil or other method to screen the house from the sunlight. However, the base line variations caused by the room temperature can be possibly corrected using the temperature data.

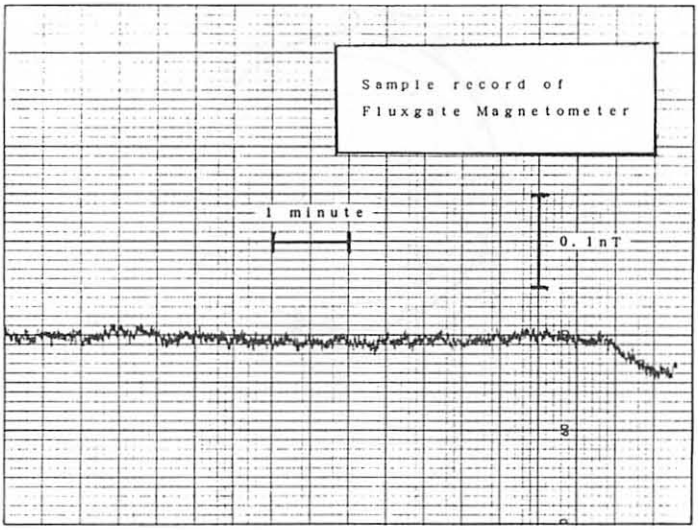

Fig. 3 Test sample of analogue record of magnetic observation by the adopted sensor core for the fluxgate magnetometer.

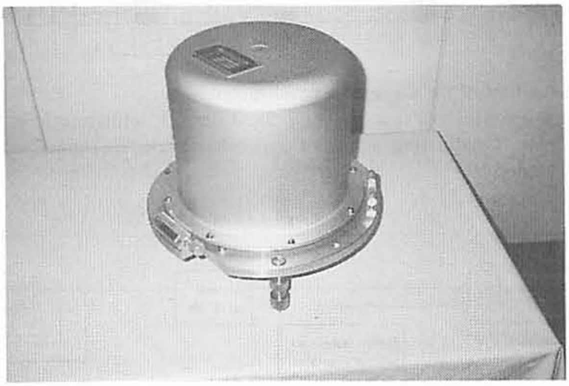

Fig. 4 The fluxgate magnetometer; Sensor unit (upper) and amplifier unit (lower).

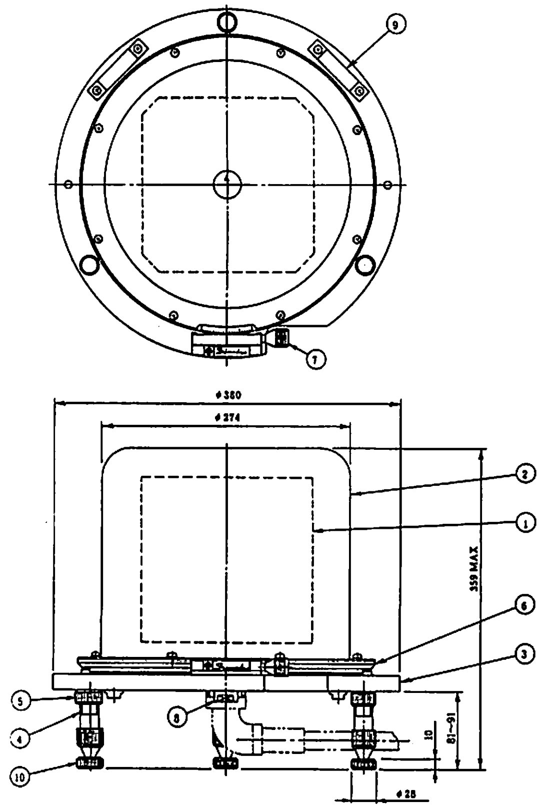

Fig. 5 Sensor unit of the fluxgate magnetometer.
1. three axes sensor body, 2. cover, 3. fixed base, 4. adjusting foot, 5. lock nut, 6. rotating base, 7. adjusting screw of azimuthal angle, 8. connector receptacle, 9. level, 10. holder.

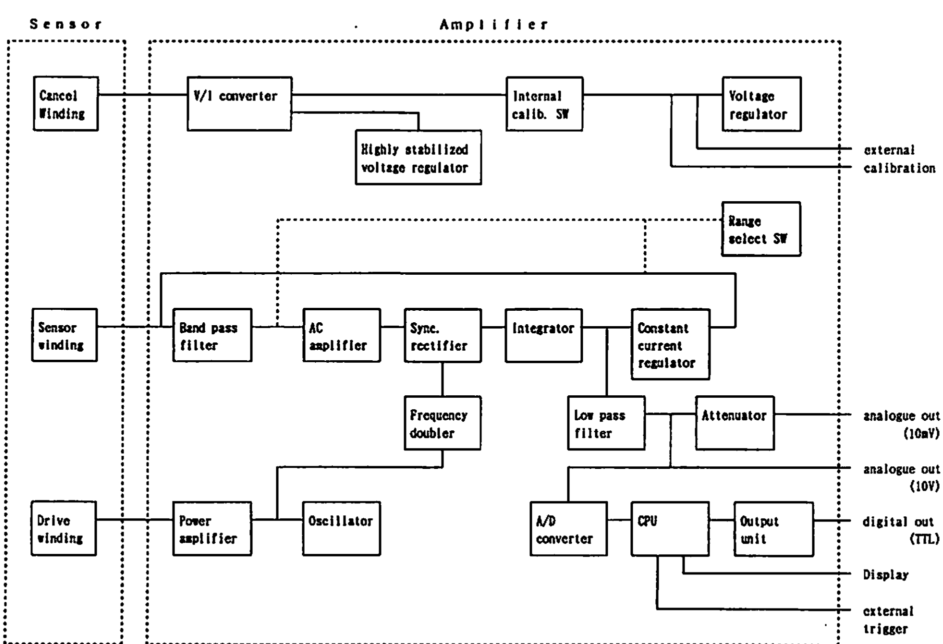

Fig. 6 Block diagram of the measurement circuit of the fluxgate magnetometer.

Table 1 Characteristics of the fluxgate magnetometer.

Sensor Type	three axes biaxial core
Accuracy of mutual orthogonality of core axes	within 6′
Sensor Drive Frequency	700 Hz
Dynamic Range	± 50 μT, ± 5 μT, ± 500nT, ± 50nT
Frequency Response	DC ～ 5Hz, DC ～ 1Hz
Noise Level	0.01 nT
Calibration Signal	± 20, 40, 60, 80, 100 nT
Output	
Analogue	± 10 V, ± 10mV ／ Full Scale of each range
Digital	16 bit binary TTL
	Sign, Over range, Data catch, Measurement range, Calibrating

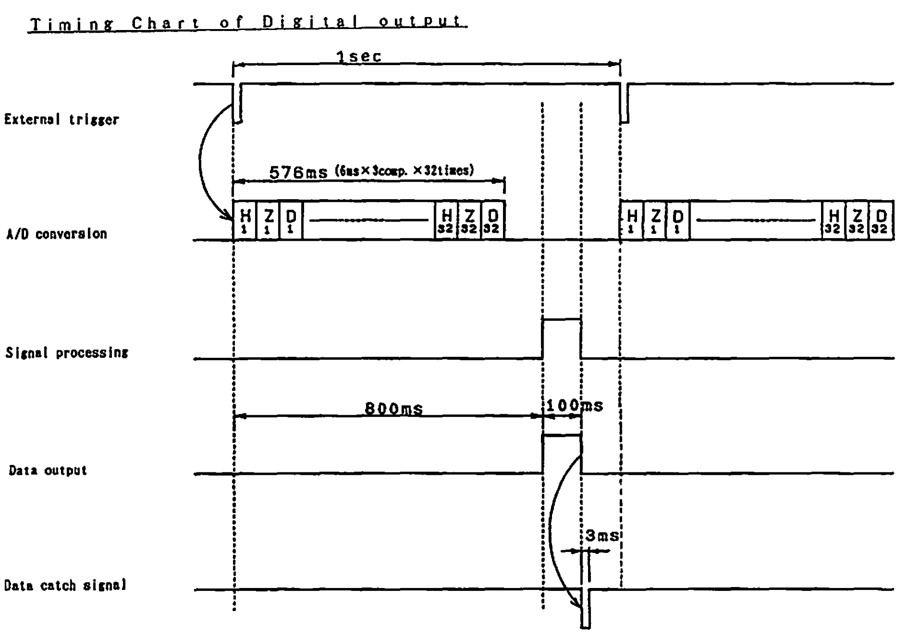

Fig. 7 Timing chart of A / D conversion of the fluxgate magnetometer.

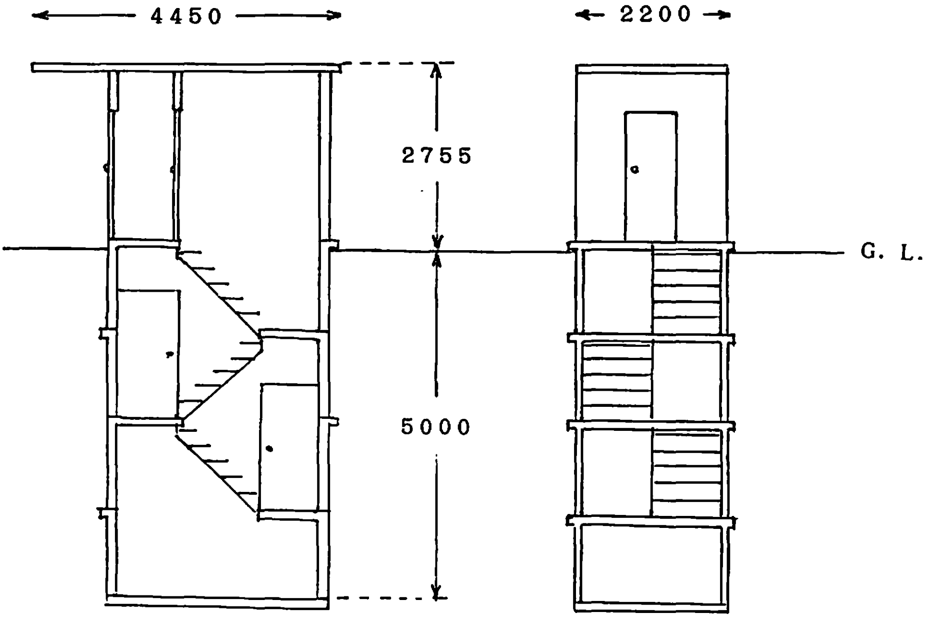

Fig. 8 The sensor house for the fluxgate magnetometer.

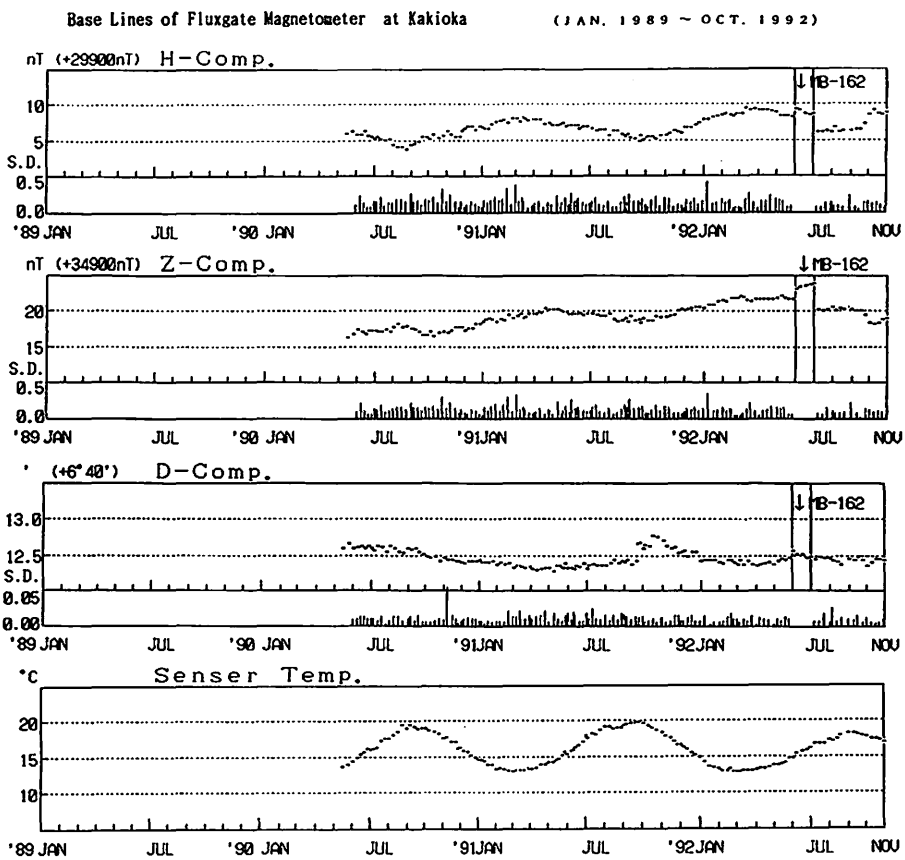

Fig. 9 Base lines of the fluxgate magnetometer (1990 May—1992 Oct.) obtained by the routine observation.

2.2 Overhauser Magnetometers and Fanselau-Braunbek Coils

Overhauser effect was at first proposed by Overhauser (1953) for the polarizing nuclei applicable only to metals. The effect was investigated as one of the methods of nuclear magnetic resonance and was proved to occur in liquids by various experimental researches. Hrvoic (1984) applied the effect to proton precession magnetometer (Overhauser magnetometer) and obtained the patent on it. Overhauser magnetometers are now manufactured by GEM Systems Inc.. The following description about the Overhauser magnetometer are based on Hrvoic (1984).

In the sensor liquid of Overhauser magnetometer, some free electrons that have unpaired spins are added. Protons in the sensor liquid are polarized effectively through weak scalar coupling with those electrons, that is, Overhauser effect. The fact that the free electrons feel the strong magnetic field of the nuclear yields further improvements to polarize protons. The electron resonance frequency is increased to more than 60 MHz, resulting in the strong polarization of protons. Thus the strong polarization of protons comparable with those of conventional proton precession magnetometers are obtained by applying oscillating magnetic field of radio frequency (RF) to the liquid.

The proton polarization is persisted so long as the RF driving is continued. Therefore, the magnetometer has a capability of continuous data sampling the rate of which can be more than one count per second. There are basically two methods to continue the proton precession (Hrvoic (1984)). For the new magnetometers (Fig. 10 and Table 2), self oscillating system is adopted. A general block diagram of the measuring system of self oscillating circuit with the frequency of proton precession is shown in Fig. 11. Thinking of the data process in the computer system, the sampling time is set same as the fluxgate magnetometer, that is, one second.

The sensor designs are shown in Fig. 12. For the component observation, only one bottle contains nitro-oxide free radical and another is a dummy bottle filled with ethyl alcohol. RF drive is applied to the both in order to keep the heat balance of the both bottles (that is an improvement from the magnetometer for total intensity observation, which was made earlier.) Therefore, it is needed to locate only the former bottle inside the uniform zone of cancel field. The sensor unit is designed to observe the perpendicular component with respect to the sensor bobbin axis. For the magnetometer to observe total intensity, the sensor bottles are cylindar type to make the sensor volume large for gaining the signal amplitude. RF drive is applied to only one of the bottles (near the connector) containing the free radical liquid for this sensor.

The characteristics of sensor liquid used for total intensity observation is different from that for component observations. The conceptual dependence curves on the magnetic field strength of the sensor liquids are shown in Fig. 13. They are experimentally derived results by GEM Systems Inc. and consistent with theory (private communication with I. Hrvoic). The #1 yields stronger signal for total intensity observation near 46,000 nT than #2. The liquid #2 is used for the component observation from 30,000 to 41,000 nT, which are the expected observational values (Table 4). Driving RF frequencies are 60.7 and 65.1 MHz for #1 and #2, respectively.

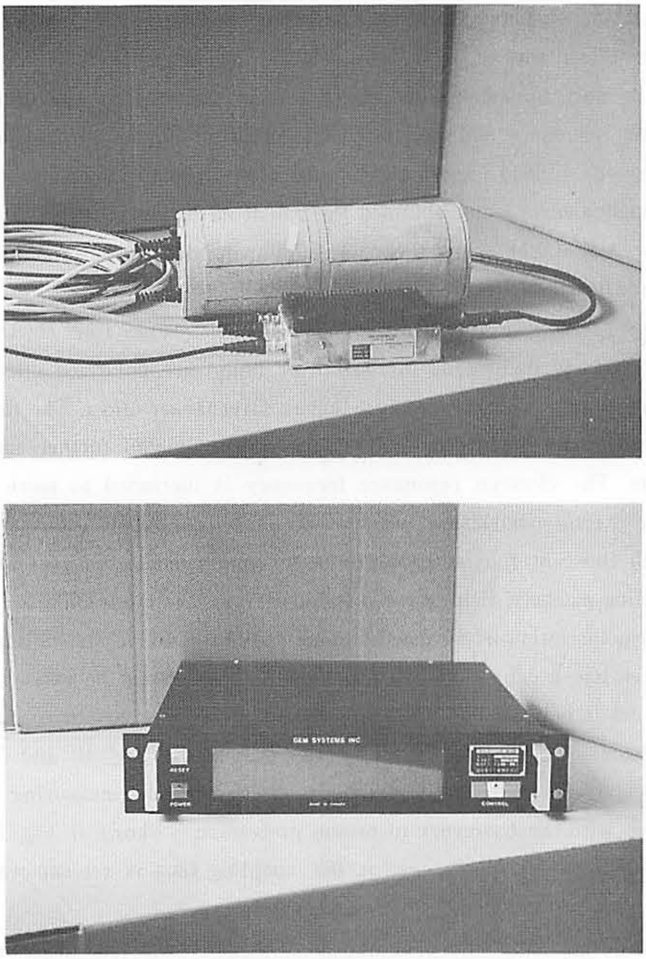

Fig. 10 Overhauser magnetometer; Sensor unit (upper) and amplifier unit (lower).

Table 2 Characteristics of the Overhauser magnetometers.

RF driving frequency	60.7 MHz (for total intensity)
	65.1 MHz (for components)
Measurement range	20,000nT ～ 100,000nT
Measurement resolution	< 0.1 nT (0.01 nT unit)
Output	
Analogue	1 V / 10nT, 100nT F.S.
Digital	RS232C
	Centronics
	BCD coded parallel 32 bit (TTL)

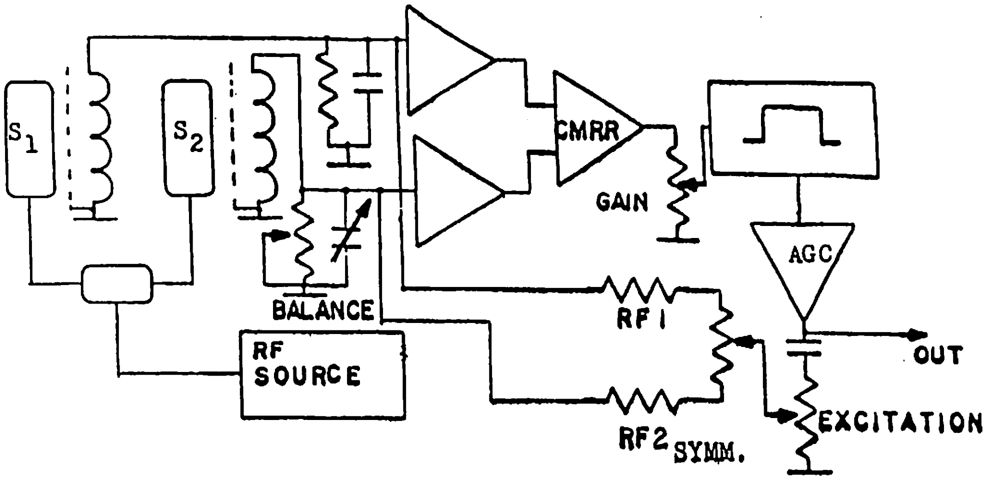

Fig. 11 Block diagram of Overhauser magnetometer measurement circuit.

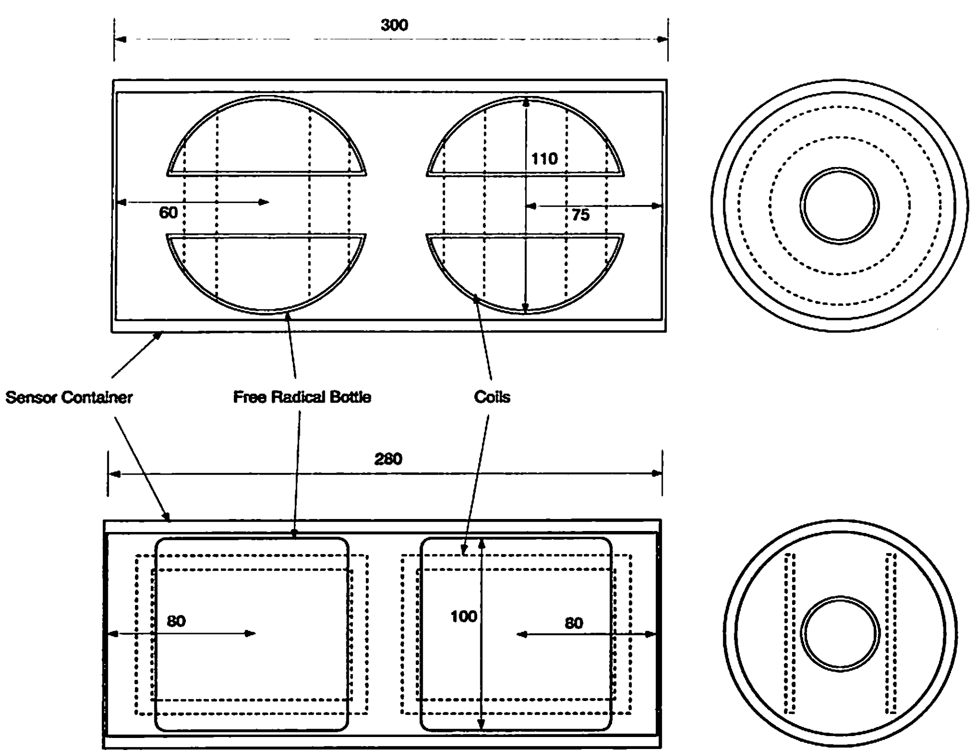

Fig. 12 Sensor design of Overhauser magnetometer; component observation (upper) and total intensity observation (lower).

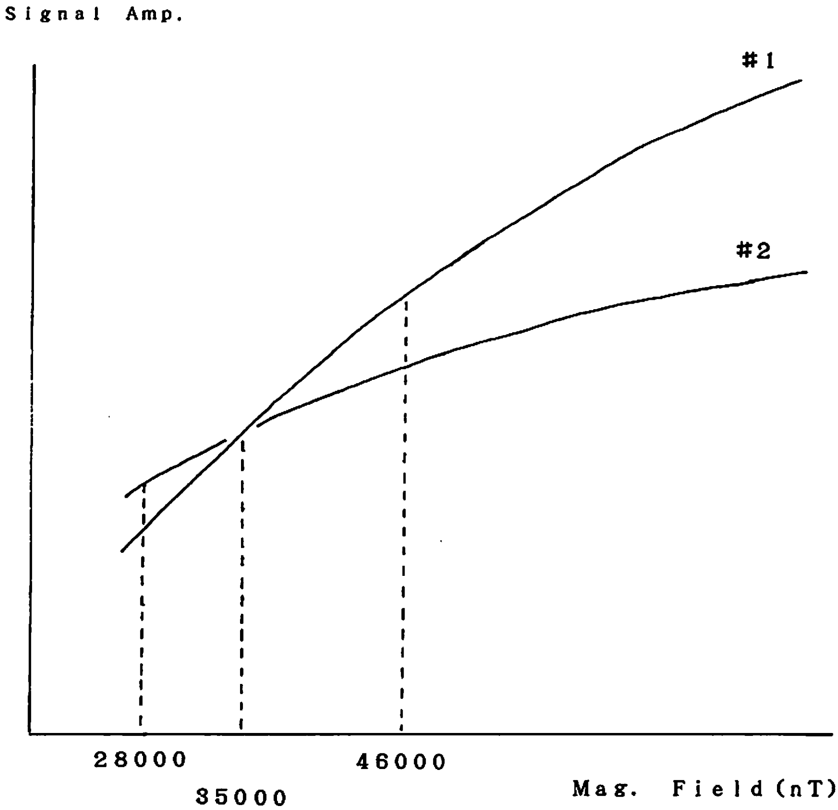

Fig. 13 Conceptual curve of dependence of signal amplitude of two kinds of free radicals, #1 and #2 on magnetic field strength.

Component observation by the Overhauser magnetometer is performed by cancelling the perpendicular component by the coils. That is the same design as the traditional method for vector proton precession magnetometers (Hurwitz and Nelson (1960), Sakuraoka (1966)), BRM of ARGOS operated by B.G.S. (Riddick et al. (1990)) and the previous optical pumping magnetometers (Sano (1971)).

Since proton magnetometers do not act well with large magnetic field gradients, the volume of magnetic field with uniformity less than 10^{-4} should be large enough to cover the sensor. The existing coils used for the optical pumping magnetometers are two mutually orthogonal Helmholtz coils with the diameters of 60 cm and 50 cm. Therefore, the size of uniform zone made by them is not more than 6 cm.

It was examined at first whether Overhauser magnetometers with small sensors less than 6 cm scales can be developed in order to make use of the existing coils. However, it was found practically impossible to yield stable measurements with such a small sensor by experiments of GEM Systems Inc.. The sensor size was finally decided as 11 cm to get the stability of measurement.

To make the uniform zone of this size by the Helmholtz coil, the diameter should be larger than 110 cm, which is too large to set on the pillars constructed in 1972 at Kakioka

Magnetic Observatory (Yanagihara et al. (1973)). Therefore, Fanselau-Braunbek design (Braunbek (1934), Fanselau (1929)) was adopted. The coil consists of two mutually parallel pairs of coils (Fig. 14). The ratios of radius of the outer coil a_2, the distances of the inner and outer coils from the center d_1, d_2 with respect to the radius of the inner coil a_1 are as follows ;

$$a_2=0.763861\ a_1$$
$$d_1=0.278053\ a_1$$
$$d_2=0.845772\ a_1$$

The coil can make approximately three times larger uniform zone in scale (twenty seven times in volume) than the Helmholtz coil. The coils were manufactured by GAUSS Corp. Japan. They are made of alminum with high accuracy and can be rotated 360° in the horizontal plane. The coil parameters are presented in Table 3.

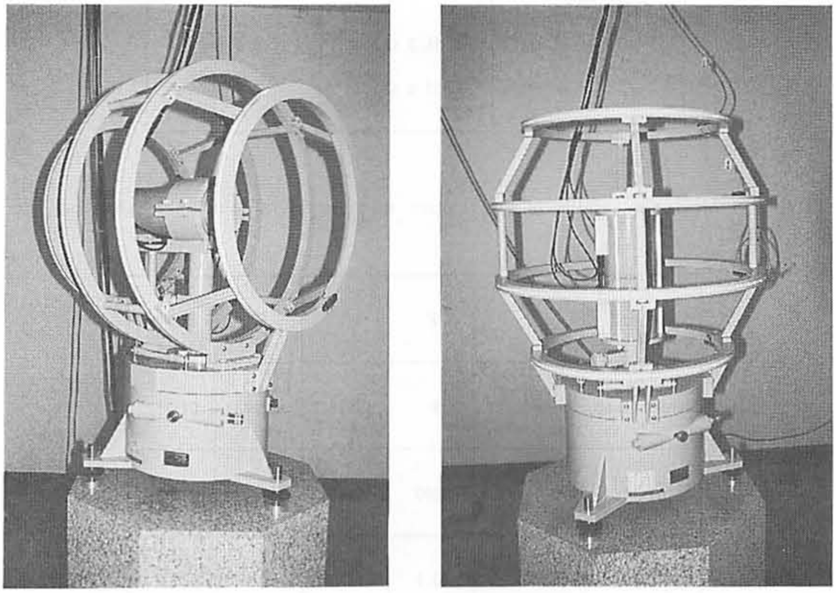

Fig. 14 Fanselau-Braunbek coils; for Z and Hyz measurements (left) and for H measurement (right).

The axes of coils are oriented vertical (H measurement), geomagnetic north (Z measurement) and 45° east of geomagnetic north (Hyz measurement), respectively. The former two measurements are almost same as those of the previous system (Yanagihara et al. (1973)) but the last one is different. As the least value of Overhauser magnetometer's measurement range is 20,000 nT, the previous Hy measurement (~15,000 nT) is out of its range. It is also mechanically difficult (or actually impossible) to make two mutually orthogonal Fanselau-Braunbek coils. The coil axis of Hyz measurement was thus directed to measure the component including the signal of geomagnetic variation of 45° west direction from geomagnetic north. The measurement status of component observations are shown in Table 4.

In the previous system, auxiliary cancel fields were superposed on the main ones to

Table 3 Factors of Fanselau-Braunbek coil.

	Main winding	Auxiliary winding
Approximate diameter		
inner coils	649.0 mm	656.5 mm
outer coils	495.5 mm	502.5 mm
Turn		
inner coils	196	28
outer coils	196	28
Coil constant	975.61 nT/mA	138.97 nT/mA
DC resistance		
inner coils	36.3 Ω	5.4 Ω
outer coils	27.6 Ω	4.2 Ω

Table 4 Measuring status of Overhauser magnetometers (the values on Aug. 12, 1993).

component	F	H	Z	Hyz
sensor name	A	D(2132)	B(2142)	C(2152)
intensity (nT)	46200	30100	35100	41000
power voltage (V)	22.5	23.8	23.3	23.9
signal level (p-p V)	0.45	0.60	0.90	1.00
noise level (p-p V)	0.20	0.50	0.20	0.20
S/N	2.3	1.2	4.5	2.7

cancel the time variation of the natural magnetic field (Yanagihara et al. (1973)). It is another important difference in the new system that the cancel fields are always kept constant with the values at the initial adjustment. Deviations of the measured values from the true values due to the time variations of the natural magnetic field are corrected by algebric calculations by the computer system.

The simultaneous equations for H (horizontal intensity, northward), Z (vertical intensity, downward) and D (declination, westward) are

$$H = H_{mes} - \frac{(Z - Z_c)^2}{2H} \tag{1}$$

$$Z = Z_{mes} - \frac{(H - H_c)^2 + (H \cdot \sin\Delta D)^2}{2Z} \tag{2}$$

$$D = D_0 + \Delta D = \cos^{-1}(Hx/H) - \theta_0 + D_0 \tag{3}$$

where, $(H, Z)_{mes}$ are (H, Z) measurements, $(H, Z)_c$ the constant cancel field strengths for (H, Z) measurements, D_0 and θ_0 the initial values (at the coil setting) of declination of geomagnetic field and the coil direction ($\sim 45°$) with respect to the geomagnetic meridian, respectively and Hx a calculated value as follows ;

$$Hx = \frac{F^2 - Hyz_{mes}{}^2 + Hx_c{}^2}{2\,Hx_c} \tag{4}$$

where, F is the measured total intensity, Hyz_{mes} the measured values of Hyz measurement, Hx_c the constant cancel field strength for Hyz measurement, respectively.

The second terms of eqs. (1) and (2) are those for adjustment during large magnetic disturbances, which have been corrected by the auxiliary cancel fields in the previous system except for the term $(H \cdot \sin\Delta D)^2$ in eq. (2).

Before the coil settings, the absolute values are obtained by manual absolute measurements on the sensor pillars. The differences of H and Z components due to the difference of sensor position are, though they are small, corrected in the following calculations when putting the measured or calculated values into F, H and / or Z in the right hand sides of the equations.

Hx is determined at first. Next, D and then Z are calculated putting H_{mes} and Z_{mes} into H and Z in the right hand sides of eqs. (3) and (2), respectively. Finally, H is calculated putting the calculated Z and Hmes into Z and H in the right hand side of eq. (1), respectively. Above calculations are continued successively putting the calculated values into these terms until the calculation converges. The base lines of the obtained solutions (we call them temporary absolute values) are corrected by absolute measurements samely as the conventional rule.

This change of correction method may result in making the hardware system simpler. The precise discussion of the designing and the error estimations for this method will be presented in another paper.

The test observations of component measurements are shown in Fig. 15. The comparisons of one minute values with optical pumping magnetometers basically showed good results. It is estimated theoretically that Hyz measurement for getting D component is most sensitive with the tilting variations of the pillar. It can be seen that D component observation fluctuates a little more than others from Fig. 15. The long term tilting variation of the pilars for the routine observation of the optical pumping magnetometers are shown in Fig. 16. The positions of F and Z sensors are exchanged and set as shown in Fig. 17

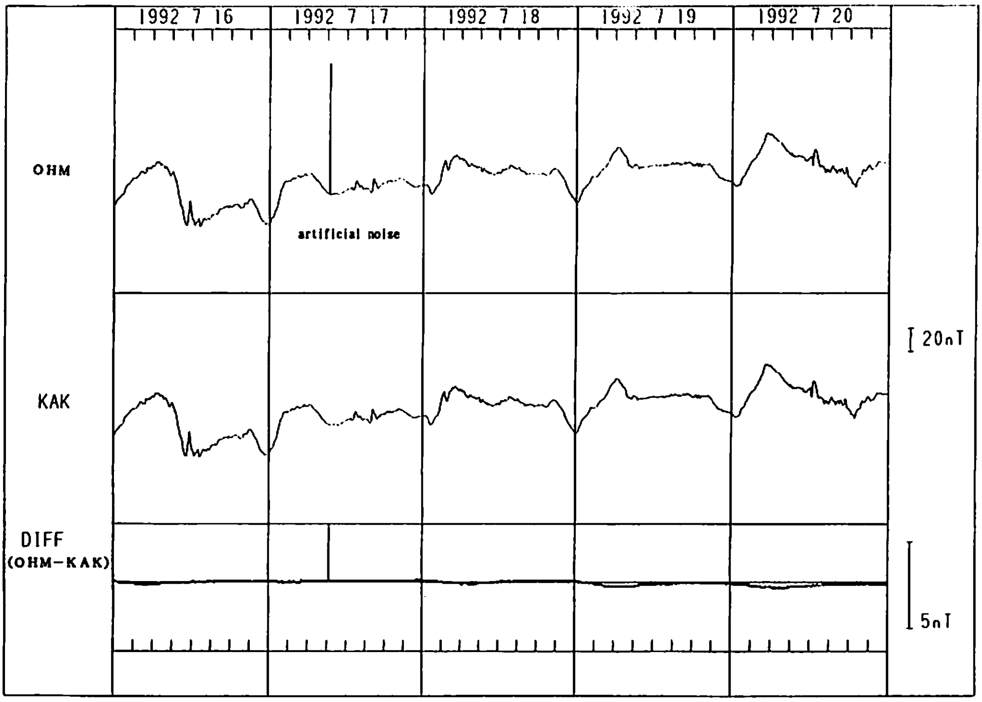

Fig. 15(a) Comparison of H component observation of Overhauser magnetometer (OHM) with KASMMER (KAK) and difference (DIFF).

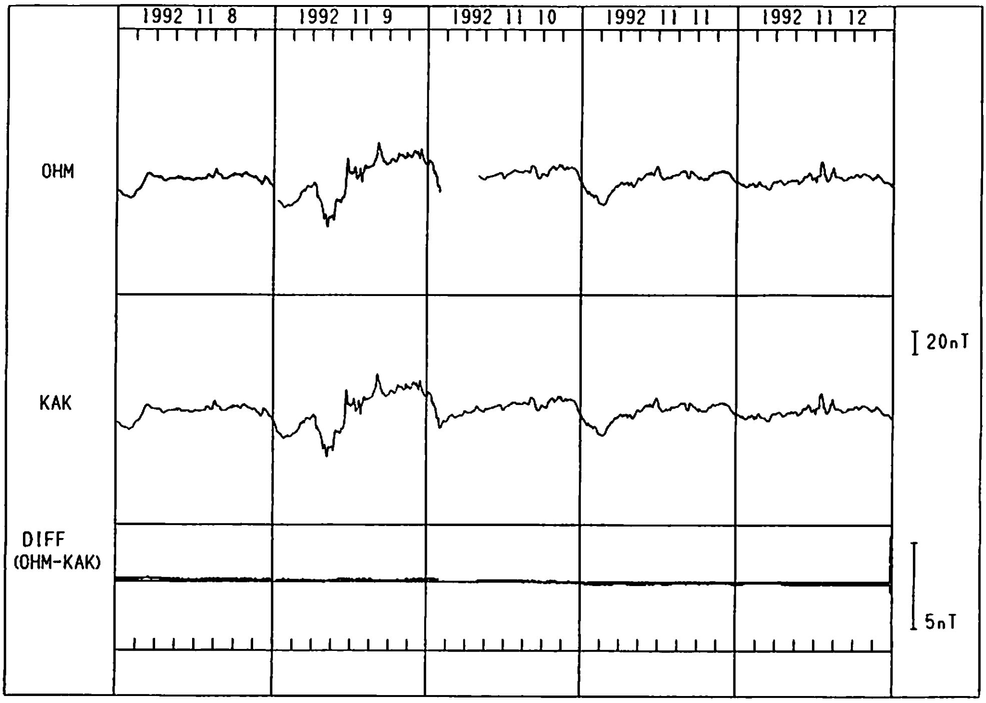

Fig. 15(b) Same as Fig. 15(a) for Z component.

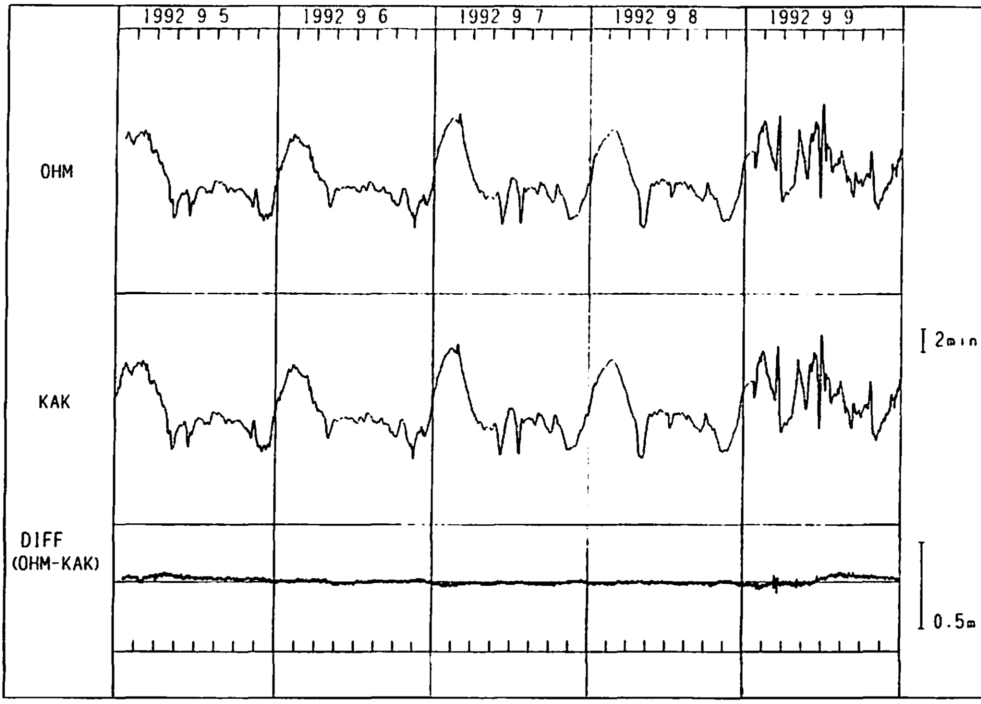

Fig. 15(c) Same as Fig. 15(a) for D component.

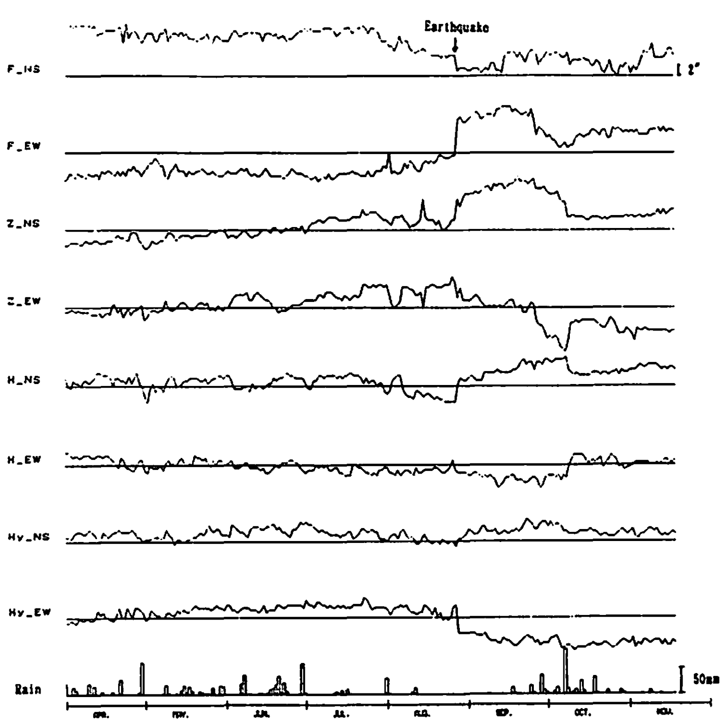

Fig. 16 Long term variations of the tilting of the pilars of the optical pumping magnetometers.

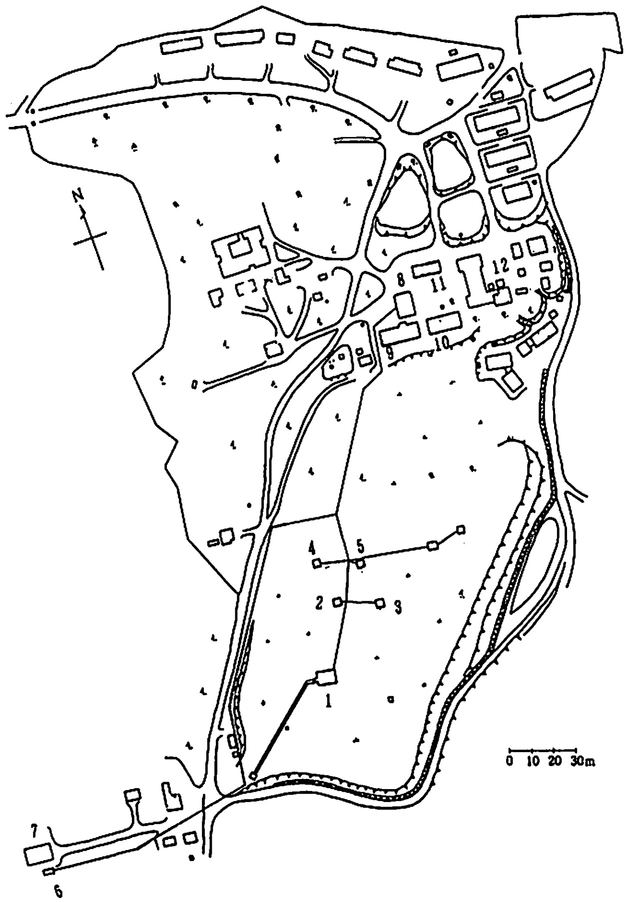

Fig. 17 Location of the sensors in the observatory ;
1 Calibration house, 2-5 Overhouser sensors for F, Z, Hyz and H measurements, respectively, 6 Sensor house of fluxgate magnetometer, 7 First absolute house, 8 Measuring house, 9 Observer's office, 10-12 Offices.

considering the dependencies on the tilting variations.

3. Data Acquisition and Processing System

3.1 Hardware of Computer System and Interface

The new computer system (Fig. 18) consists of six Hewlett Packard's RISC based work stations (HP 9000/700 series) and a SPARC station of Sun Micro Systems. The ethernet cables connect all the work stations. Two work stations (The first and the second ones from the left in Fig. 18. We call them WS-A and B hereafter.) receive and record the observed data in their hard disks in parallel. HP 9000/700 series, having good MTBF (Mean Time Between Failures) values, are suitable for these machines which are imposed heavy duty of nonstop data recording. Other work stations support the compatibility with WS-A and B except the SPARC Station. Data processing is operated using one of others (the fifth one from the right. We call it WS-C hereafter.) in the observer's office. Thus, the

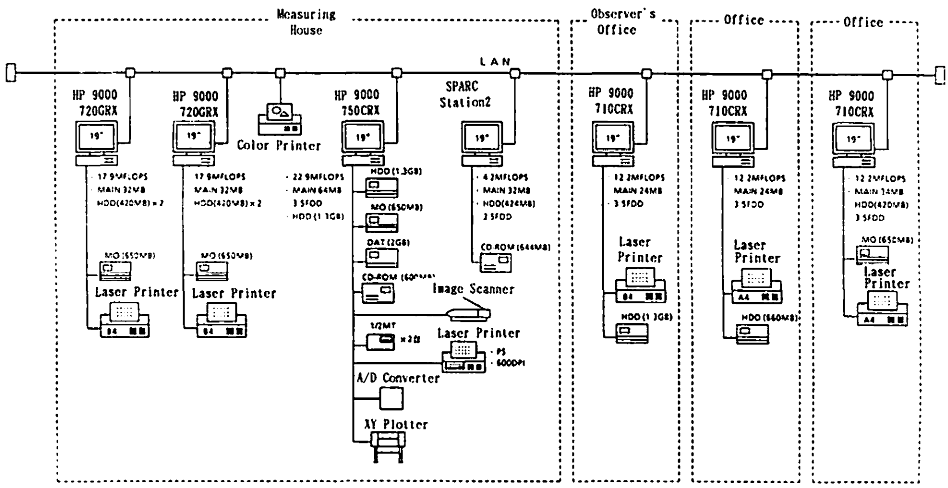

Fig. 18 The new computer system.

data recording part in the system is made compact comparing with the previous system. Other four work stations are used for data exchange and researches, data processing of Earthquake and volcanic observations, making indices and administration of network (including the network with other organizations through telecommunication lines).

All the machines are power-supplied through UPSs which protect the short term power drops with 10 minuites capacity. For the machines in the measuring house, shutdown process will be automatically started by the AutoShut Down Units at the long term power drops to avoid the damaging of the UNIX file system. The power line for one of the UPSs which supply the power only for WS-A in the measuring house is switched to the line of auto generator when the long term power down occurs. The UPSs in the measuring house are power supplied through surge absorbers and optical fiber ethernet cables are laid outside the offies as the measures for protection against lightning induced currents.

The block diagram of the data transmission from the magnetometers is shown in Fig. 19. The data from the magnetometers are all transmitted as TTL level signals to the interface (DASBOX 8300A by Systems Design Service Corporation in Japan). All the ten kinds of data (time code, H, Z, D components of fluxgate, F, H, Z, D ones of Overhauser, F of proton precession magnetometer and a dummy) are BCD coded and occupy 32 bit data width. They are transmitted to DASBOX 8300A in each second. Therefore the total number of data bits per second is 320. The collected data are then transmitted altogether from DASBOX 8300A to WS-A or B through DMA interface.

The magnetic tape drives are persisted in the new system for the standard data exchange because it is not established for the world wide compatibility by other media. However, the magnetooptical (MO) disk systems will be mainly used for the data storage. One MO disk can store two years records of one second values, while one magnetic tape can 6 months of those at most. The printers are all laser printers without traditional line printers. X-Y Plotter is equipped for making the plots equivalent to magnetograms.

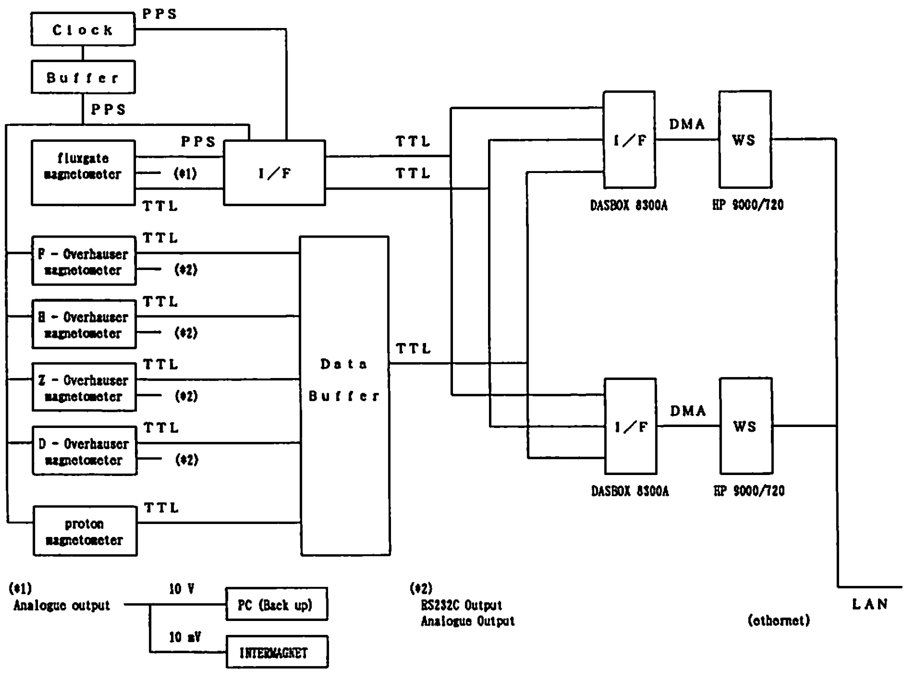

Fig. 19 Block diagram of signal transmission process from the magnetometers to the work stations.

3.2 Software for Data Acquisition and Processing

The softwares for acquisition and processing of the magnetometer data are newly made. There are basically three groups of programs; data acquisition, data processing for absolute measurement and data processing to obtain final values. The program names and their basic functions are shown in Table 5. In the following sub–sections, rough introductions of these programs will be given.

3.2.1 Data acquisition and monitoring of one second values

Since the constant data recording is the most important role for the computer system, the software for data acquistion was carefully designed. The software needs a setting of the priority of the process by the operating system to avoid data missings due to the busyness of the CPU in multi process environment. The priority setting is usually not supported enough by UNIX system, especially those based on BSDs. The HP-UX, based on System V, supports strong priority setting and was expected to serve the sufficient condition for constructing data acquisition program.

In the previous mini computer system, the data acquisition program which was designed for only one set of magnetometers performed various processes beside the data acquisition and rercording. It automaticaly calculated one minute and hourly values based on the one second absolute values which were obtained using temporary base line values and recorded these calculated values in the hard disk files. It was also designed to show the

Table 5 Program names and their functions.

Data acquisition and monitoring of one second values	
pg1	Data acquisition
pg1m	Real time monitoring of the receiving data
pg1a	Receiving the alarm signal from pg1
Data acquisition and processing for absolute measurement	
pg3a	Data acquisition of proton precession magnetometer
pg3b	Data acquisition of fluxgate and Overhauser magnetometers at absolute measurement
pg3o	Calculation of base line values
Data processing to obtain base line controlled one minute values	
pg6	Display and print out of the data
pg7	Copy of part of the original data
pg7x	Making temporary one second values
pg8	Revision of the parameters for pg1
patch	Arrangement of the data files
c2x	Making final one minute values
c2h	Calculation of hourly values
pgi	Initialization of final data files
plotb	Plotting the magnetographs

data status on the character display when an operator interrupts.

The program for the new system is basically designed as simple as possible. It passes the original data to hard disk files without calculations of temporary one minute values or hourly values. It checks the data continuity after the conversion of the transmitted data from BCD to integer and operates only a few other processes, such as sending the alarm signal to WS-C through ethernet when the data are irregular. The data acquisition program is designed to start automatically just after the power on of WS-A and B.

Original one second data are written in three files all of which have same structure as follows ;

1. H, Z and D components of the fluxgate magnetometer and F of Overhauser magnetometer.
2. H, Z, D and F components of Overhauser magnetometers.
3. F component of proton precession magnetometer and dummy.

To monitor the status of data acquisition, an operator can start another program for the data monitring on the X Window system of WS-A and / or B. The monitoring program continues to update the magnetogram in each second. Time span of the monitor is several minutes (Fig. 20).

3.2.2 Data acquisition and processing for absolute measurement

There are basically two procedures operated on the computer system at each absolute

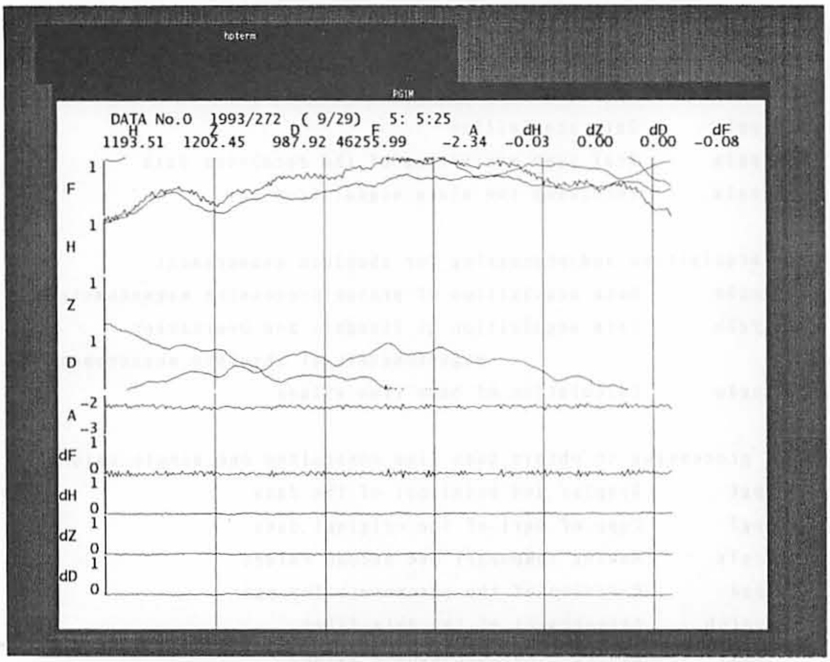

Fig. 20 An example of the graphic output for real-time data monitoring on the display of WS-A using X Window system.

measurement. One is to obtain the difference of the total intensities observed by the proton precession magnetometer at the absolute observation point and by Overhauser magnetometer. At this time, the sampling rate of proton precession magnetometer is raised to 1 counts per 6 seconds. The another procedure is to pick up the data of fluxgate and Overhauser magnetometers just at the time of absolute measurement.

These programs basically couple with the date acquisition one. The real time data is got through the common memory with the latter. The proton precession magnetometer measurements and the time of the absolute measurements are indicated by flags of data bits. The data corresponding to the absolute measurements are recorded in the appropreate files. Character output is shown on the display for the confirmation of success of the process.

The base lines of magnetometers are calculated afterwards. The daily base line determination is done monthly with several absolute measurements per one month, which is the same time schedule as the previous system.

3.2.3 Data processing to obtain the base line controlled one minute values.

As the first stage of data processing, the original one second values are arranged with respect to time and compiled as the temporary absolute values for each magnetometer set. This process, operated on the basis of one second values, needs high performance of the computer system but the RISC based work station of Hewlett Packard can afford to complete the process without much delay. The temporary absolute values are processed to the final one minute values after the base line derivation by absolute measurements and corrections of irregular data. Data flows together with the respecting programs are summarized in Fig. 21.

Data quality is checked by the trigonometric check and examining the differences between the data of fluxgate and Overhauser magnetometers (same as the methods explained by Kuwashima (1990a)). Fig. 22 shows the example of the plots by laser printers used in the data correction process. The programs are all operated on X Window system.

4. Brief observational results by the new system

The replacement of the sensors of the previous optical pumping magnetometers with those of Overhausr magnetometers were performed in spring of 1993. The new system including the computer system started the observations from April, 1993.

The computer system has not been caught by any serious troubles after the start. No data missings due to the software bugs or irregularities of operating system have occurred.

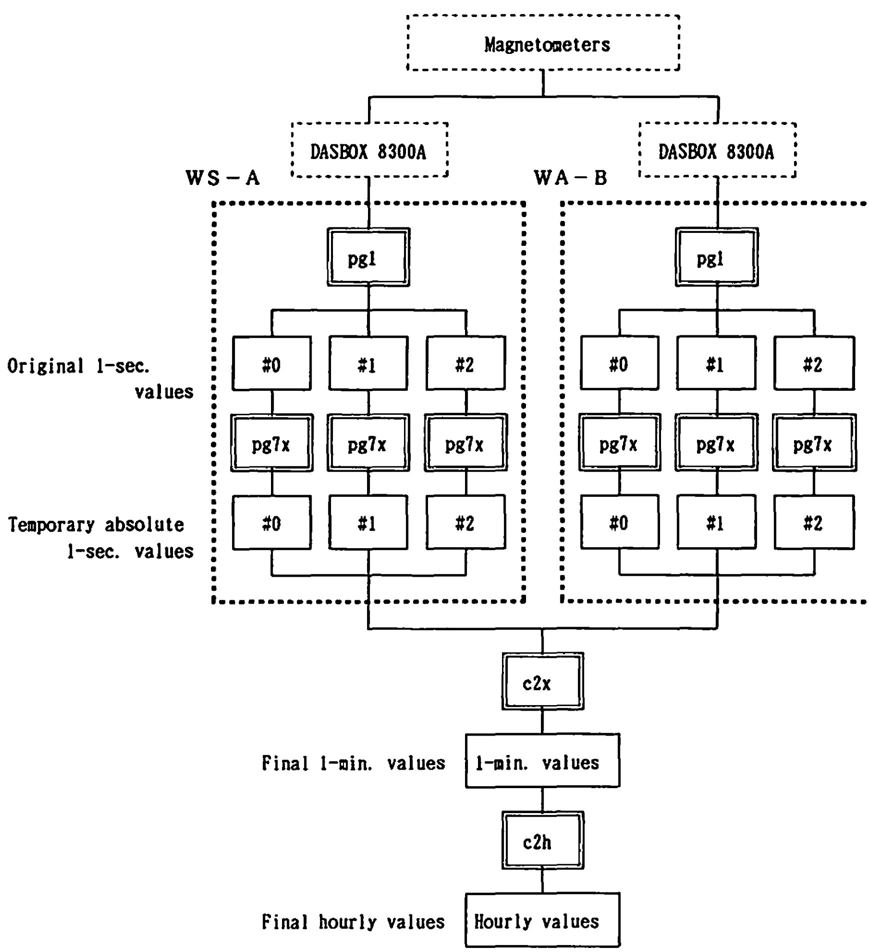

Fig. 21 Flow of the data processing. Hardwares, data files and corresponding programs are in dashed, solid and double squares, respectively.

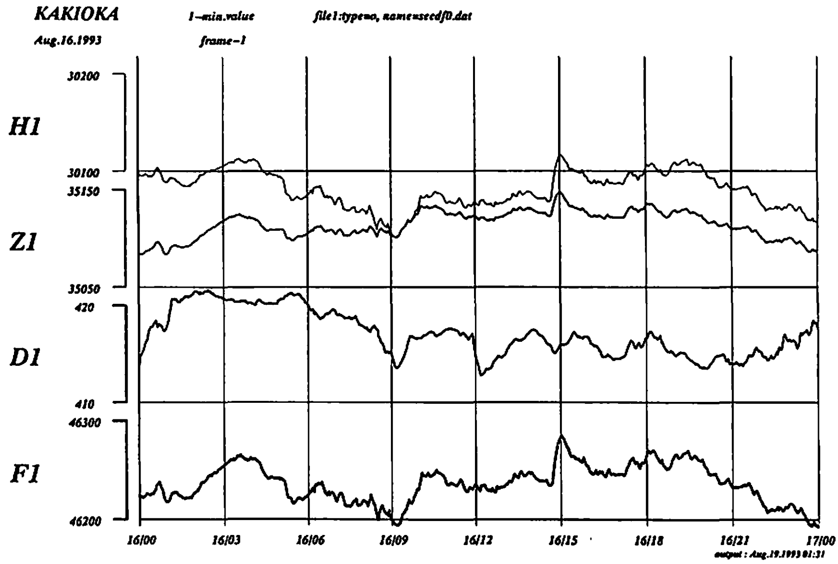

Fig. 22(a) Original data of the fluxgate magnetometers.

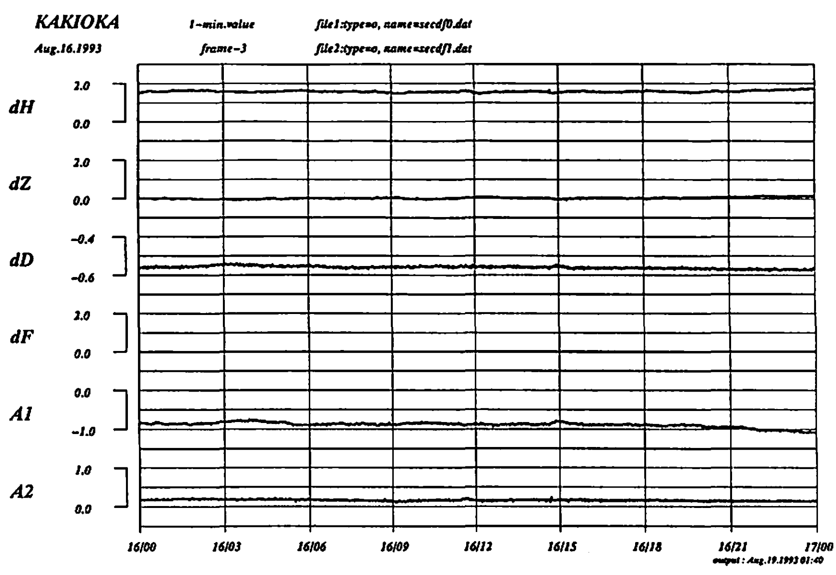

Fig. 22(b) Differences between two magnetometers (dH, dZ, dD) and A-values ($F - (H^2 + Z^2)^{1/2}$) for trigonometric check. A1 is for the fluxgate and A2 for Overhauser magnetometers.

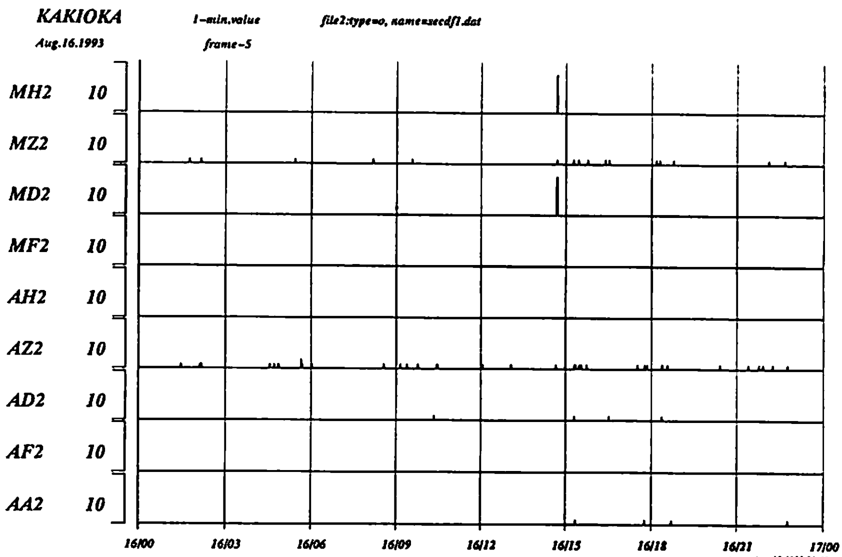

Fig. 22(c) Counts of missing data (MH2, MZ2, MD2 and MF2) and irregular data (AH2, AH2, AD2 and AF2).

The increasing of the data are compensated by the speed up of the computer system. Therefore, the data processing labours are not increased by the increase of the data amounts. The LAN system is also useful for the data handling.

Fig. 23 shows the comparison of component observations of the fluxgate magnetometer and Overhauser magnetometers. The drift of D component difference is ascribed to the data

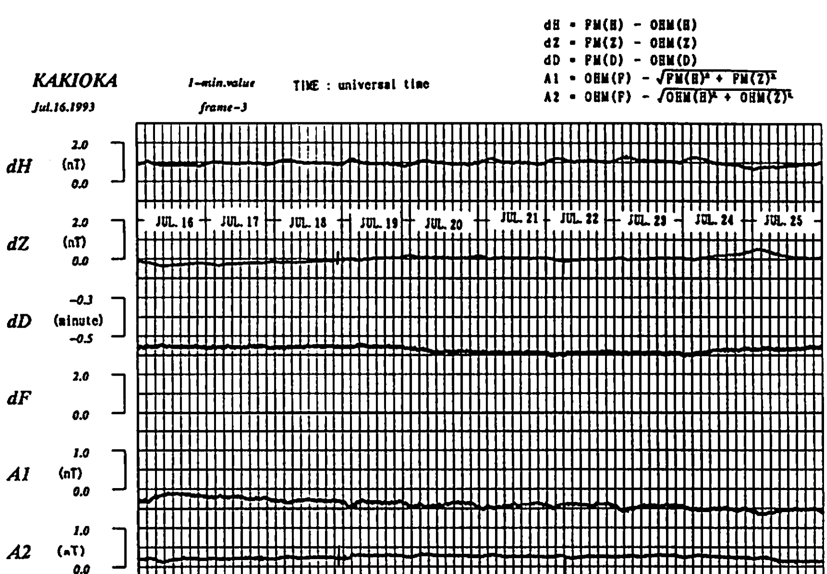

Fig. 23 Comparison of component observations of Overhauser magnetometers, OHM (H), OHM(Z), OHM(D), OHM(Z) and those of the fluxgate magnetometer, FM (H), FM(Z), FM(D).

of fluxgate magnetometer. By A1 and A2 values, it is shown that Overhausers act well in the stability of observation.

The next problems are how to make the synthesized system including the two branch offices at Memambetsu and Kanoya and how to interconnect the network with those of other organizations through telecommunication lines. For both matters, the new computer system will contribute to proceed such projects. We hope the system will soon be possible to communicate with GINs of INTERMAGNET through networks extending to the world.

Acknowlegement

We would like to make appreciations to succesive directors of Kakioka Magnetic Observatory, Dr. R. Murakami, Mr. K. Karouji, Dr. S. Kubota and Mr. M. Tezuka for their encouragements for this work and to Messrs. M. Churei, Y. Mizuno, K. Koike, K. Nakaya, S. Kadokura, S. Nakajima, H. Sakai, T. Yamamoto and T. Oowada and other colleagues of Kakioka Magnetic Observatory for their kindful suggestions and technical co-operations. Dr. M. Kuwashima arranged the plan of the replacement project of KASMMER at the initial stage and gave us useful suggestions.

The high sensitivity fluxgate magnetometer, Overhauser magnetometers and Fanselau-Brunbek coils were made by Shimadzu Corp., GEM Systems Inc. in Canada and GAUSS Corp. Japan, respectively. Kokusai Electronics Corp. arranged and supplied the system of Overhauser magnetometers, Fanselau-Braunbek coils and some interfaces. The sensor house of the fluxgate magnetometer was constructed by Hirasawa Corp. using the resin concrete frames made by Hakusan MFG. The interface of the work stations to get the magnetometers data were made by Systems Design service Corp.. The computer system was designed and supplied by NTT Data Communications Systems Corp. in co-operation with Focus Systems Corp. who was engaged in coding the software. We would like to appreciate the following people for the efforts in developing the techniques of the new magnetometer system; Mr. T. Yoshikawa (Shimadzu corp.), Dr. I. Hrvoic (GEM Systems Inc.), Mr. Y. Sekine (GAUSS), Messrs. S. Uzu, Y. Tanaka and H. Eura (Kokusai Electronics Corp.).

Making and working of the budgets are approved by Japan Meteorological Agency with the aid of the observations management division of the observations department of Japan Meteorological Agency.

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柿岡標準磁気儀の新システム

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概　　要

柿岡の標準磁気儀（KASMMER）の変化観測測定器が1989～1992年にかけて4年計画で更新された．新しい測定器は高感度フラックスゲート磁力計1式およびオーバーハウザー磁力計4式とファンスロー・ブラウンベック・コイル3式の組み合わせである．前者は高分解能の毎秒値を，後者は安定した基線値を得るためのものである．約1年間にわたる調査観測の後，これまで20年間用いられてきた光ポンピング磁力計がオーバーハウザー磁力計と置き換えられ，1993年4月より新測定器による定常観測が開始された。これまでスタンドアロンのミニ・コンピューター2式であったコンピューター・システムも，イーサネットで接続された7台のUNIXワークステーションで構成されるものへと更新された。この報文で我々は，KASMMERの新システムの設計を紹介し簡単な観測結果を報告する。