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25. *Some Equipments Used in Microtremor Measurement.*

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1. Introduction.

Our studies concerning microtremors have been carried out from about ten years ago from the standpoint of engineering seismology, and systematic measurements of microtremors have been made at more than a thousand places in Japan and the U. S. A. In these measurements some equipments, which we call the "microtremometer", designed especially for microtremor measurement were used. The first microtremometer of visible type was constructed in 1953 and offered us much valuable data in the early stages of the study, but it was not very satisfactory in its characteristics and construction. Since then the equipment has undergone frequent improvements.

On the other hand, with the increase in utility of the results of microtremor measurements to earthquake-proof construction designs, it became more necessary to increase efficiency in analysis as well as in measurement. A magnetic recording type microtremometer and a period distribution analyser have been devised and constructed to suit these requirements. These equipments have been in use for several years in good order, so somewhat detailed descriptions of them will be presented here. The period distribution analyser will be reported in another paper.

2. Visible type microtremometer using a smoked paper.

The vibrations of the ground measurable in normal times are a superposition of different kinds of waves generated from natural and artificial sources, and their frequencies ranging from about 0.1 cps to about 100 cps. The vibrations of about 0.5 to about 20 cps are dealt with in our microtremor study. As a matter of fact, microtremors, compared with microseisms and the artificial disturbances near the origin, are rather small in amplitude, especially in undisturbed countries. The maximum amplitudes of microtremors in Tokyo, for example, are less than one-tenth of that of microseisms even in the daytime of a calm day. Consequently, it is necessary to use vibrographs having frequency characteristics of band-pass type, to extract the microtremors only from the actual ground vibrations.

Under these considerations, we chose the natural frequencies of 1 cps and 20 cps respectively for a transducer and a recorder in our microtremometer. The amplitudes of microtremors vary widely according to the subsoil condition of the respective places and are in the range of about 0.01 micron to 1 micron. The microtremometer should be capable of over 100,000 times magnification at maximum and a reducible magnification is necessary in order to record microtremors with the appropriate amplitude on a recording paper. On the other hand, we have been using a frequency-period diagram in the analysis of microtremors. This method of finding the period of predominant vibration of the ground is expedient and more feasible than other methods of analysis. It was considered from the investigation on the "ripples" of earthquake motion[1] that for determining the predominant period of ground by means of frequency-period analysis of microtremors, the use of a velocity type vibrograph might be more effective than a displacement type. Therefore, a velocity characteristic was adopted for the first microtremometer and midnight observations were made by using a time-switch to avoid high frequency disturbances, which are remarkable in the daytime. In order to overcome such an inconvenience a low-pass filter has been added to the amplifier circuit of the microtremometer.

A brief description of the first microtremometer (EMS-1) has previously been reported in the bulletin[2]. The first equipment had some unsatisfactory features in that the amplifier had no low-pass filter and could not adjust the gain finely, and in addition the equipment was too large. The design and construction of the visible type microtremometer, which is an improved type (EMS-6) overcoming the above-mentioned defects, is explained

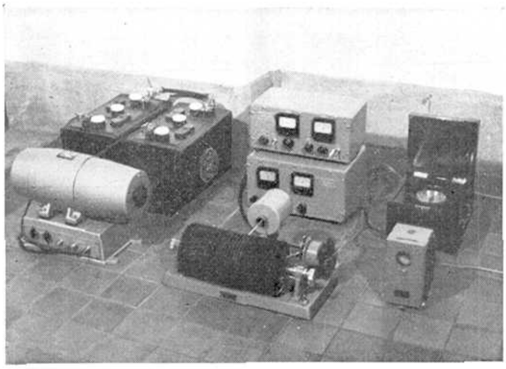


Fig. 1. Assembly of the visible type microtremometer.

1) K. KANAI, K. OSADA and S. YOSHIZAWA, *Bull. Earthq. Res. Inst.*, **32** (1954), 361.
2) K. KANAI and T. TANAKA, *Bull. Earthq. Res. Inst.*, **32** (1954), 199.

as follows:

The appearance of the equipment is shown in Fig. 1. The equipment consists of a transducer, an ultra-low frequency amplifier, a recording device and a power supply.

1) Transducer. The photograph in Fig. 2 shows the construction in detail of the horizontal motion transducer designed for the present purpose.

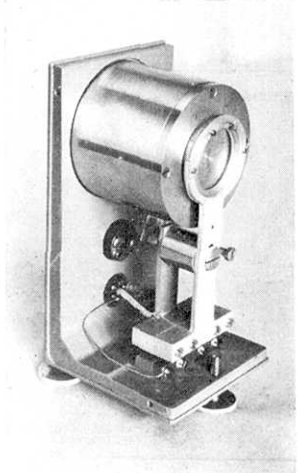


Fig. 2 Horizontal motion transducer.

The transducer is of moving-coil type with an inverted pendulum having a natural frequency of 1.0 cps. The pendulum is attached with a small mass of brass which is movable along the pendulum arm. The moment of inertia of the pendulum can be changed by the aim of the mass and the natural frequency of the pendulum ranged approximately from 0.9 to 1.1 cps. This is useful for adjusting the frequency of each pendulum of many transducers to the assigned value. The voltage sensitivity of the transducer is 2.4 volt/kine and its total weight is 3.7 kg.

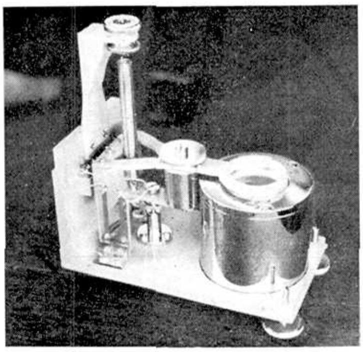


Fig. 3. Vertical motion transducer.

The vertical transducer shown in Fig. 3 was also constructed by us. The pendulum is of Ewing's suspension type and the vertical helical spring is made of invar wire. The design and constants of the vertical transducer are almost the same as the horizontal one. In addition to these transducers of usual type we also constructed the special transducers, with pendulums of natural frequency 1.0 cps, for bore-hole and sea-bottom use[3]. A peculiar self-levelling system was adopted for these transducers, because a pendulum having a natural frequency of under about 3 cps is necessary to keep its supporting bed level.

2) Recording device. An electromechanical recording method using a smoked paper is adopted in the recording device. The device may be distinguished by the penmotor. It was some ten years ago that the

3) K. KANAI and T. TANAKA, *Bull. Earthq. Res. Inst.*, **36** (1958), 359.

prototype of the penmotor was constructed[4].

The constructional features and the photograph of the penmotor used at present are illustrated in Figs. 4 and 5. There is little difference

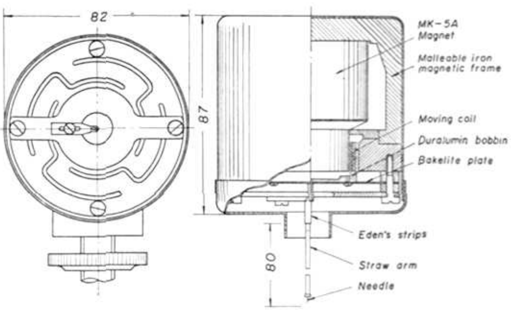


Fig. 4. Constructional features of the penmotor for the microtremometer.

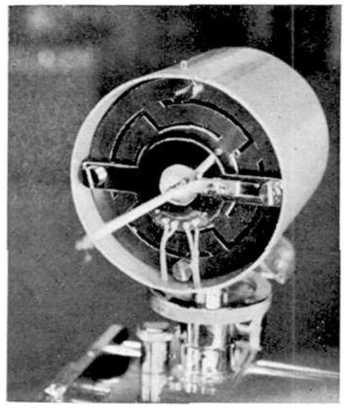


Fig. 5. The penmotor.

in construction between the two except for the dimension minimized by the improvement of its magnetic circuit. This moving-coil motor element is well illustrated in the electrodynamic loudspeaker used widely in the field of acoustical engineering. The motor element consists essentially of a coil bobbin of duralumin on which wires are wound in two parts and is suspended free to move in a strong magnetic field. The moving-coil is attached to the one side of Eden's twin strips[5] (the other side is fixed to the frame), and a back and forth motion of the coil is changed into a rotary motion without any friction and play. The magnification of the system is given approximately by the ratio of the full length of the recording pen (L) to the distance between both strips (D). In our case, L is 9 cm and D is 0.3 cm, so the magnification of the movements of the coil at the tip of the pen becomes about 30. The twin strips were constructed of a phosphor-bronze plate of thickness 0.1 mm. The natural frequency and DC sensitivity of the penmotor were designed to be 20 cps and 0.5 mA/mm, respectively. The resistance of each winding of the coil is 600 ohms. The vibration system including the coil and magnifying mechanism is activated by the electromagnetic damping due to the duralumin coil bobbin. In Fig. 6 is shown the relation between the coil current and the deflection of the tip of the

4) T. TANAKA and K. KANAI, *Journ. Seism. Soc. Japan*, [ii], **5** (1952), 43 (in Japanese).

5) G. NISHIMURA, M. SUZUKI and E. FURUKAWA, *Bull. Earthq. Res. Inst.*, **32** (1954), 87.

recording pen of the penmotor. The difference in the sensitivity for the right and left directions of the pen is less than 1 percent. The frequency response of the penmotor is sufficiently flat as seen in Fig. 7.

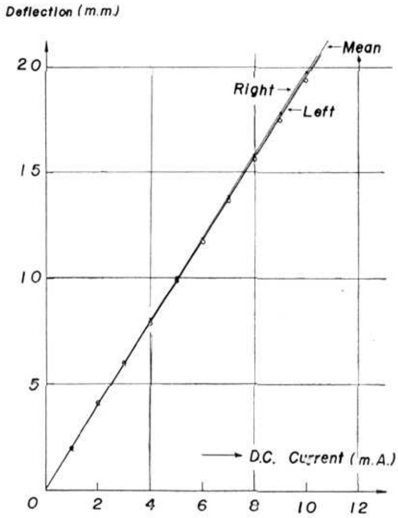


Fig. 6. Relation between the coil current and the recorded amplitude of the penmotor.

In this recording device a drum type paper driving system using a smoked paper is used. The recording drum is 40 cm in periphery and rotates at a fixed position in 40 sec. The penmotor shifts 0.8 cm sideways in every rotation of the drum. The record for 18 minutes is traced on a smoked paper with a paper speed of 1 cm/sec. In usual microtremor measurement, about three minutes of recording time is taken for each place. So that the microtremors at six places may be recorded on a smoked paper without exchanging the paper. The recording device is furnished with an automatic switch that cuts off the power source when the penmotor slides to the terminal of the guide rail. Midnight observations may be done easily by using this with a time-switch. The recording device is shown in Fig. 8.

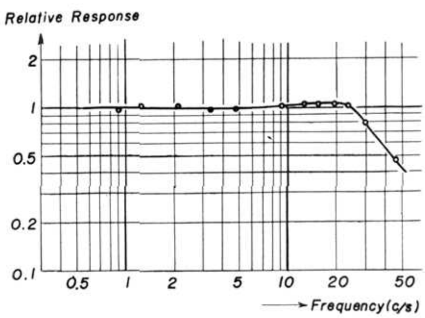


Fig. 7. Relative frequency response of the penmotor.

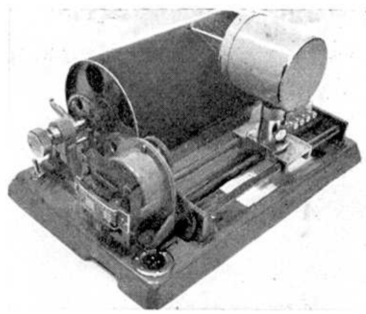


Fig. 8. Recording device with a smoked drum and a penmotor.

3) Amplifier and power supply. It was estimated roughly from the sensitivities of the transducer and the penmotor that an amplifier having the total mutual conductance of at least 30 mhos is necessary to record the microtremors of amplitude 0.01 micron at 1 cps to 1 mm

trace amplitude on a recording paper. The amplifier circuit consists of four cascaded stages of twin triodes and pentodes in push-pull, and provides a mutual conductance of approximately 30 mhos in total. Time-constants of coupling RC elements are 1~2 sec. As is well known, the push-pull connection of amplifier circuit has great advantages, that is, good linearity and good stability in operation. The frequency response of the circuit is very flat in a range from 0.5 cps to 100 cps as shown in Fig. 9. In the amplifier circuit two steps of RC low-pass filtering elements are contained. The amplifier is provided with two precise attenuators to control the gain. The overall magnification of the microtremometer may be reduced to one thousandth of its maximum with a step of 2 db. A special time marking method is employed for the microtremometer. Time marks are registered on the recording paper by interrupting the output of amplifier at every 15 sec. by using a specially made clock. These marks are also utilizable as a zero line of the recorded waves. The electric power for the amplifier and the driving motor of the recording device is supplied from an AC 100 volt inverter driven by a 12 volt battery in the case of field measurement.

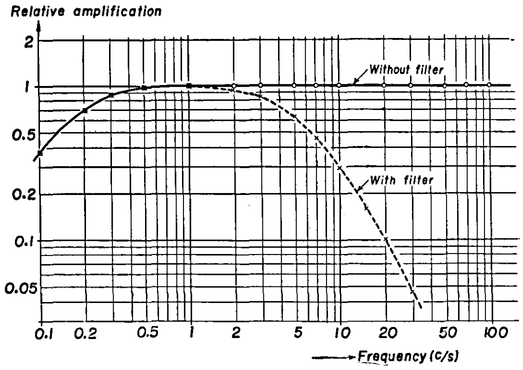


Fig. 9. Frequency response curves of the amplifier for the visible type microtremometer.

4) Frequency characteristics. Fig. 10 shows the overall frequency response curve of the microtremometer which was used in the early stages of our microtremor study. In that equipment the frequency response of the amplifier was flat, and the microtremometer performed as a velocity vibrograph. As previously stated, the use of a velocity vibrograph is more reasonable for our study of microtremors, but this type of vibrograph is easily influenced by high frequency disturbances caused by traffic, etc. In

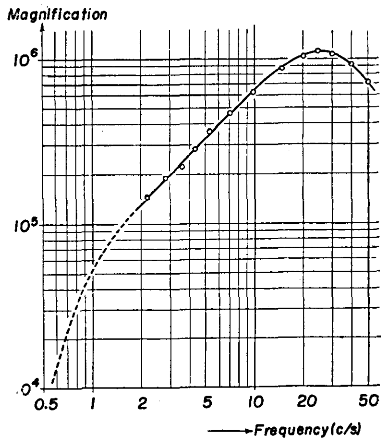


Fig. 10. Overall frequency response of the EMS-1 microtremometer.

order to get around such difficulty in practice, the microtremometer containing a low-pass filter was made, which enabled us to make observations even in the daytime. Fig. 11 shows its frequency response. Although the frequency characteristics of later type equipment varies from that of former type, it has been found that the difference between them is not serious from the engineering point of view.

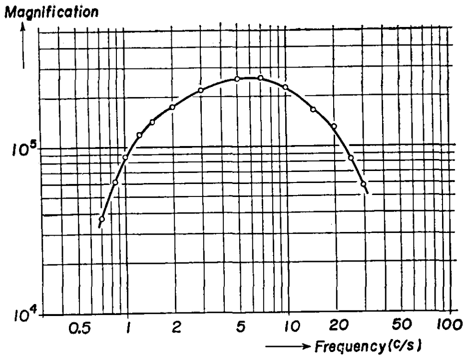


Fig. 11. Overall frequency response of the EMS-6 microtremometer with a low-pass filter.

3. Magnetic recording type microtremometer.

The microtremometer mentioned above is useful for field measurements to obtain immediate information of ground properties through visible record. But it is too laborious to read off the periods of waves by means of a scale directly from a record. A period distribution analyser has been constructed to avoid such an inconvenience by automatizing the procedure of period analyses. The magnetic recording type microtremometer has been made as a recording part of the analyser. The principal points considered in the design of this microtremometer are as follows:

a) It is an essential requirement for this equipment to have the same performance characteristics as the visible one.

b) The pulse width modulation (PWM) system is preferable for the magnetic recording of microtremor signals, because it is more effectual for the high fidelity recording of the ultra-low frequency waves than other types of modulation, and is hardly affected by fluctuation of tape speed.

Repetition frequency of the carrier pulses should be determined as higher than the highest frequency in the signal waves. Usually the frequency ratio is chosen as approximately 10. In this equipment a frequency of 400 cps was adopted when considering the frequency range of microtremors. For the purpose of getting good stability and accuracy of frequency, a quartz-crystal oscillator is employed as a generator of the pulse. A somewhat higher tape speed is required in the PWM system than in other modulation systems. However, a strict uniformity of tape speed is unnecessary. Therefore, a commercial magnetic tape recorder is employed in this microtremometer and the tape speed of 19 cm/sec is adopted.

The circuit composition of the magnetic recording type microtremometer is illustrated schematically in Fig. 12, and its assembly is shown in Fig. 13.

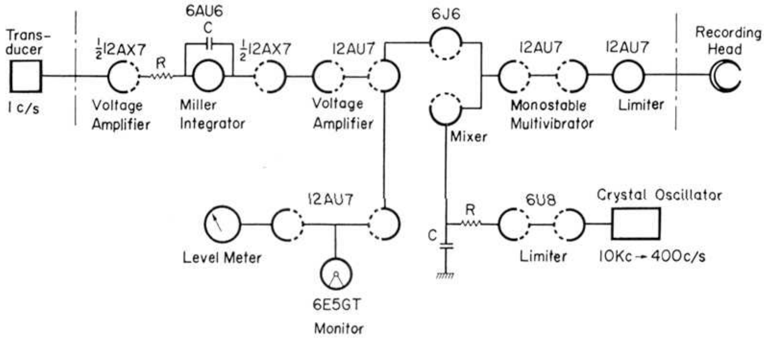


Fig. 12. Schematic diagram showing the circuit composition of the magnetic recording type microtremometer.

1) Amplifier. The microtremor signal from a transducer is first amplified in the former stage of an amplifier and passed through the Miller integrator to convert it into the signal proportional to the displacement of the ground vibration. This output signal is amplified once more in the latter stage until a sufficient voltage is obtained to drive the modulator. The amplification obtainable amounts to 82 db and is finely reducible to one-thousandth of the maximum, with an interval of 2 db, by suitable combinations of two precise attenuators. The Miller integrator having a time-constant of 0.05 sec. integrates considerably the input signal waves of the frequency above 0.5 cps as seen in Fig. 14. It will be seen in Fig. 14 that the response of the amplifier without integrator is also flat enough in the requisite range of frequency.

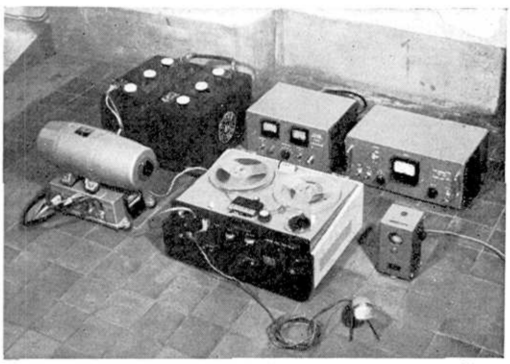


Fig. 13. Assembly of the magnetic recording type microtremometer.

2) Modulator. The pulse width modulated signals are derived by changing the grid potential to the earth of the monostable multivibrator, which is proportional to the integrated microtremor signal voltage. The full transistorized crystal oscillator (OTC-1P) is used as the carrier pulse generator, and its nominal frequency stability is as good as 10^{-5} in normal operation. The 400 cps sharp pulses for triggering the monostable multivibrator are obtained by the frequency division from the 10 kcps output rectangular waves of the oscillator by the process as seen in Fig. 12. The carrier pulses thus obtained and the signal waves from the amplifier are fed to the modulator tube after they are mixed. The pulse width modulated signals are then led to the recording head of the magnetic recorder through a limiter. Fig. 15 shows the characteristics of the modulator. The non-distortion maximum input voltage to the modulator is about 5 volts and it corresponds to approximately 0.5 millivolt input voltage to the amplifier at 1 cps with the full gain of the amplifier.

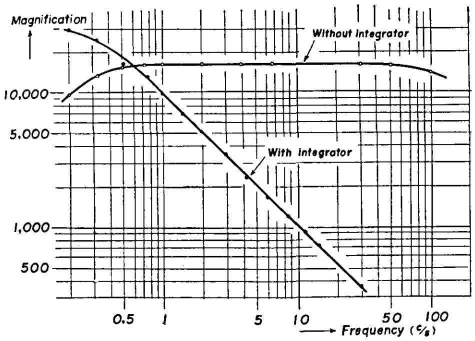


Fig. 14. Frequency response curves of the amplifier for the magnetic recording type microtremometer.

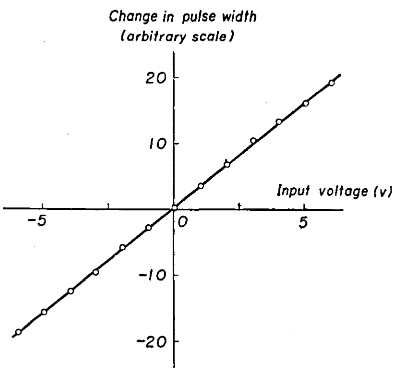


Fig. 15. Characteristics of modulator. Abscissa: input voltage to a modulator. Ordinate: change in the width of the output pulses from the modulator.

3) Magnetic recorder. In our equipment, Model 361 Tapecorder of SONY is used. This model of magnetic recorder is provided with a hysteresis motor, and both 19 cm/sec and 9.5 cm/sec tape speeds are available. The wow and flutter is less than 0.3 percent.

4) Signal level indicator. The amplifier-modulator unit is fitted with two different types of signal level indicators. One is a magic-eye type which shows the transient values of the signal voltages and the other is a pointer type voltmeter which indicates the time mean. The magic-eye is calibrated to allow maximum recording levels without distortion when

the green lights just close.

5) Power supply. This type of microtremometer also employs the battery-inverter system for supplying the necessary power to the units. The governor-controlled inverter which is provided with a frequency adjuster and a frequency meter is used. The heater current for the tubes is supplied from a battery through ballast tubes to keep it constantly from the voltage variations of the battery.

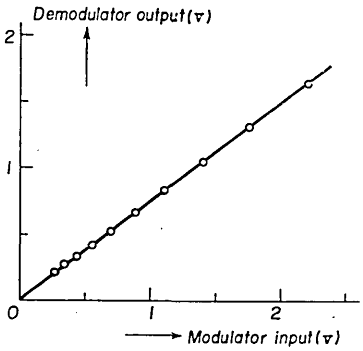


Fig. 16. Modulation and demodulation characteristic curve (passing through the magnetic tape.) Abscissa: input voltage to the modulator. Ordinate: output voltage from the demodulator.

The microtremor signal recorded on the magnetic tape can be reproduced on a recording paper through the tape reader and the demodulator which are contained in the period distribution analyser. Details of this part will be explained in another paper.

The relation between the output voltage from the demodulator and the input voltage to the modulator is shown in Fig. 16. The signal to noise ratio of the reproduced record was reduced as low as -47 db. Overall frequency characteristics of the magnetic recording type microtremometer are illustrated in Fig. 17. The calibration was done by means of the shaking table. The maximum magnification of this equipment attains to about 300,000 times, and may be reduced to about 300 times by the use of the attenuators. The simultaneous records of the microtremors at neighbouring places by two types of microtremometers are shown in Fig. 18. In Fig. 18, (a) and (b) represent respectively the records obtained by the visible and the magnetic recording type equipment.

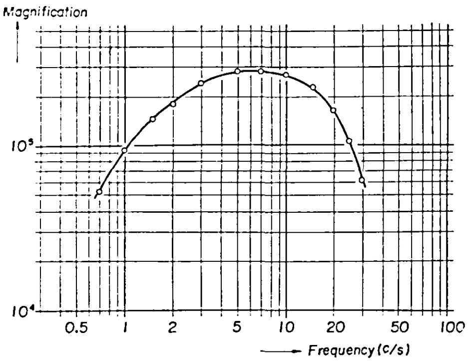
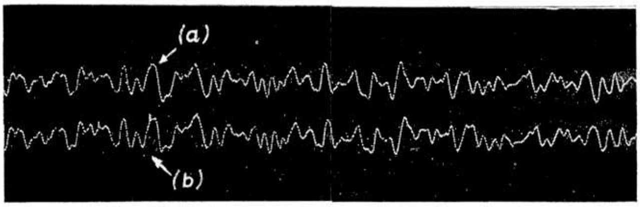
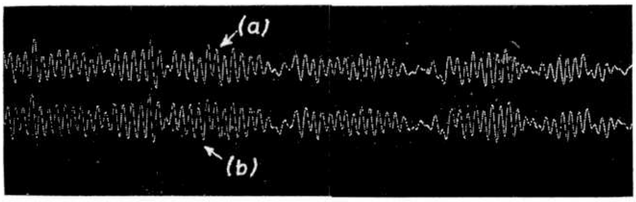


Fig. 17. Overall frequency response of the magnetic recording type microtremometer.



Records of microtremors on the ground.



Records of building vibrations caused by microtremors.

Fig. 18. Simultaneous records of the microtremors at neighbouring places by two types of microtremometers. Original × 1/2.
(a): Direct record of the visible type microtremometer.
(b): Reproduced record of the magnetic recording type microtremometer.

4. Conclusion.

We have described in this report two types of measuring equipment designed especially for microtremors. One of the microtremometers is of visible type, which has many advantages in field measurement. The other is of magnetic recording type constructed as a recording part of the period distribution analyser. The microtremor measurements at more than a thousand places have been carried out with these equipments, and they are still supplying us abundant satisfactory data. The microtremor signal recorded on the magnetic tape can be analysed easily and promptly by the analyser. The demodulated electric signal is also applicable for other sorts of analyser.

In conclusion, the writer wishes to express his sincere thanks to Dr. Kiyoshi Kanai who gave him constant guidance and encouragement.

25. 常時微動計の製作

地震研究所 田 中 貞 二

常時微動の測定用として記録方式のちがう二つの常時微動計を製作し，現在までに数千におよぶ測定を行つてきた．その一つは動線輪型の Penmotor を使つて煤紙記録を行うもので，最初の計器は約十年前に作られたが，その後種々の点で改良されてきた．この計器は直視型のため，測定現場で直ちに地盤特性を推定できる利点があり，常時微動の測定には甚だ便利である．しかし，得られた記録から，周期の頻度分布図を作るための読取り作業は，そう容易ではない．

常時微動の工学的応用面がひらけてくるにつれて，解析作業を能率化することが必要となり，周期頻度解析器が試作されたが，その記録部分として作られたのが磁気録音式常時微動計である．録音にはパルス巾変調方式を採用して満足すべき性能が得られている．これらの常時微動計は 1～20 c/s の地動を選択記録するような帯域沪波特性をもち，最高約 30 万倍の記録倍率をもつものである．