# Some New Instruments used in Earthquake Engineering in Japan.

By Etsuzo Shima, Teiji Tanaka and Nozomu Den.

In this paper the authors have not intended to make a general report of the instruments used in earthquake engineering circles in our country, but have confined themselves to descriptions of those instruments for which they themselves are responsible. Owing to space limitations only brief description are given here.

The instruments described here include the seismometers or vibration meters and similar instruments and vibration analysers. Since the earthquake engineering at present is mostly concerned with the problems in civil engineering, the band width of the vibration frequency dealt with here is confined to the range between a few tens and tenths per second. The ideal vibration meters are postulated to have so flat a response characteristic that no corrections are necessary for ordinary purposes in the frequency range required. As for the accelerographs hitherto used in earthquake observations, the sensitivities are not high enough for general use and they drop abruptly for motions with higher frequencies than 10 c/s.

In the chapter 1 of the present paper is described an electromagnetic instrument to cover such a defect without any use of an electronic amplifier which may often cause undesirable variations of the amplification constants. A displacement meter and a dynamic pressure guage on a similar principle are also reported.

In the second chapter a type of analyser of irregular motions is described. This apparatus automatically sorts different periods of irregular vibrations into prescribed intervals, and counts the numbers of occurences of the periods of each groups in a given length of time. In this apparatus the class interval of the period is taken as almost constant in the logarithmic scale, and statistical distribution of the periods in the class intervals are to be obtained in the same length of time as that of the observations.

In the last chapter is given a description of an apparatus to analyse automatically similar irregular vibratory motions by calculating their auto- or cross-correlation functions. The use of correlation functions was introduced in the field of communication engineering, and proved to be very powerful in the elucidation of the characteristics of filters and other networks. In civil engineering problems, structures and soil layers near the surface may be treated as filters, and the response to irregular disturbances such as ground tremors can be used to calculate the relevant correlation functions, which in this case turn out to be the self oscillations of the structures and others.

## 1 Seismometers and other instruments

By Nozomu Den.

In order to make precise measurements of vibrations of a constrution during an earthquake, it is necessary to use seismometers which have good characteristics in many respects. Firstly, to investigate the modes of vibrations and strains, it is desirable to record vibrations of various parts of a construction on the same paper. Secondly, it is well known in the statistical seismology that the numbers of earthquake occurences are proportional to the reciprocals of their magnitueds. Thus the use of high sensitive instruments for earthquake observations can reduce the necessary time to obtain abundamt data. Thirdly, the seismometers must have good **linearity,** satisfactory frequency characteristics and so on.

The above mentioned requirements must be closely met especially to study vibrations of constructions which are built on hard rock foundations usually found at damsites and other places, and have high natural frequencies.

Having these requirements in mind, we designed the following new electrodynamic accelerometers, displacement seismometers and hydrodynamic gauge. They are used in combination with attenuators and an electromagnetic oscillograph, and the whole equipments are controlled by a transistorized starter.

## 1.1 Accelerometers

The horizontal accelerometer DK-3CH shown in Photo. 1.1a is provided with a horizontal pendulum, while the vertical accelerometer DK-3CV in the Photo. 1.1b consists of a Ewing suspension pendulum with a vertical helical spring. To each of these pendulum is attached a coil that moves in the field of a strong magnet, and the pendulum is damped electromagnetically so heavily that its forced motion in itself is proportional to the velocity of the ground motion in a frequency range from 0.3 to 30 cps. The current induced in the moving coil is thus proportional to the acceleration of the earthquake motion in the assigned range of frequency.

The equation of motion of the pendulum is given by

$$K\ddot{\theta} + D\dot{\theta} + U\theta = - MH\ddot{x} - GI \tag{1.1}$$

where $\theta$ represents the angular displacement of the pendulum due to ground motion x and influenced by the current I that flows through the moving coil, and M and K represent the mass and moment of inertia of the pendulum respectively, while H is the distance of the centre of gravity from the rotation axis. U and D in the above equation indicate the moments of the restitutive and damping forces corresponding to unit angular displacement and velocity respectively, while the constant G is the so-called voltage sensitivity to the angular velocity of the pendulum as is indicated by the following formula:

$$I = G\dot{\theta} / (R_c + R_{ext}) \tag{1.2}$$

in which $R_c$ and $R_{ext}$ are the electric resistances of the coil and the external circuit respectively.

It can be shown, in the present case, from equations (1.1) and (1.2) that the following relation holds approximately in the above mentioned frequency range.

$$\frac{G^2}{(R_c - R_{ext})} \dot{\theta} = - MH \ddot{x} \tag{1.3}$$

Consequently, the sensitivity of the accelerometer is given by

$$S = \left| \frac{I}{\ddot{x}} \right| = \frac{MH}{G} \tag{1.4}$$

which shows that the sensitivity depends only on M, H and G and not on the natural frequency of the pendulum and the resistance of the circuit. If instead of the output current of the pendulum, a direct current equivalent to S is fed into the input of the attenuator, the overall sensitivity can be calibrated easily and accurately.

The frequency characteristics of these accelerometers are very flat as shown in Fig. 1.1. The maximum overall sensitivity of these accelerometers, as combined with attenuators and galvanometers in the oscillograph can attain 4 mm/gal even when the natural frequency of the galvanometers are as high as 50 cps.

### 1.2 Displacement Seismometer

The horizontal seismometer DK-1CH and the vertical seismometer DK-1CV are constructed on the same principle with the accelerometers described above except that the masses and the periods of the pendulum of the displacement seismometers are larger than those of the acceleration seismometers. The current induced in the moving coil of the pendulum, which is damped somewhat less than critically, is proportional to the velocity of the ground motion for a frequency above the natural frequency (1 cps) of the pendulum. This current is led to an integrating type galvanometer so that the recorded motion of the galvanometer is proportional to the displacement of the frequency above 1.5 cps where the response characteristics shown in Fig. 1.2 is constant. The maximum overall magnification of this instrument attains to 1000 times which may be reduced by the use of an attenuator.

### 1.3 Hydrodynamic Pressure Guage

The dynamic pressure of water in a reservoir, due to an earthquake motion, will act strongly upon the surface of a dam. This problem was dealt with theoretically by H. M. Westergaard and others, and experimentally by several investigators. It is important to measure this hydrodynamic pressure during actual earthquakes. A new type of a hydrodynamic pressure gauge was designed for this purpose.

The cross-section of this gauge is shown in Fig.1.3. It has two vessels filled with silicon oil. The first vessel is separated from the outside water by a large bellows of little stiffness, and the second one has a magnet in it. These vessels are partitioned off by a small bellows, to which a coil to move in the field of the magnet is attached.

When the hydrodynamic pressure acts upon this gauge, the pressre is transmitted through the oil in the first vessel and the small bellows, and acts upon the second vessel. Consequently the silicon oil in the second vessel is compressed and the coil moves in proportion to the pressure. To avoid the effects of the variations of the hydrostatic pressure and temperature, two vessels are connected by a long and fine pipe, through which the oil can move from one vessel to the other quasi-statically but not dynamically.

The current induced in the coil is proportional to the time derivative of the pressure, and when the gauge is used in combination with an attenuator and a galvanometer of integrating type, the hydrodynamic pressure can be recorded. The total sensitivity attains to 200 mm/(kg/cm$^2$).

## 2 Period Distribution Analyser for Irregular Motions By Teiji Tanaka.

For the analysis of irregular motions such as earthquakes, micro tremors of the ground and noises, the distribution of zero crossing intervals (half periods) have been advantageously used broadly. We have also used it more than one thousand times in the analyses of micro tremors of the ground and building vibrations caused by such tremors. It is revealed that maxima of the frequency curves of periods obtained thereof occurs at the periods of proper or dominant oscillations. This method of elucidating the characteristics of ground or structural vibrations is expedient and more feasible than other method of analyses. But to read off the periods by means of a scale directly from a record is very clumsy and hence liable to observational errors.

To evade such an inconvenience, it is desirable to automatize such a procedure. Instruments for such a purpose have been made and used in acoustical studies, but their frequency band is quite different from that in earthquake engineering. So we tried to construct an apparatus for the analyses of irregular motions in the frequency band from 20 to 0.4 cps. The lowness of the frequency band concerned in our problem presented some difficulties not encountered in the acoustical problems. We have been able to overcome these difficulties and construct an apparatus which will be reported in this paper.

The analyser consists of several parts which perform the following operations.

### 2.1

The vibration recorded on the magnetic tape by PWM system is taken out as an electrical signal through the tape reader (with the same tape speed when it is recorded), and the demodulator.

The signal can be differentiated or integrated when it is necessary. The demodulated original signal can be mechanically recorded on a recording paper, and the necessary time marks for it are to be obtained by frequency-demultiplying the modulated pulses of 400 pps which may be taken out when the tape is read.

2.2

This demodulated signal is compressed in amplitude by passing through the compresser having nearly logarithmic characteristics. Then it is sent through the square wave forming circuit to be converted into a square wave with a constant amplitude, keeping the same period as the signal. On the other hand pulses of 200 pps obtained by the frequency demultiplication from 10 kc crystal oscillator are applied to the simultaneous gate circuit whose gate pulse is the above mentioned signal of the square wave. Thus the pulse of 200 pps passes through the gate circuits only when this gate pulse has positive voltage. In this way the quantization of the signal square wave is accomplished, and the length of the positive interval of the square wave can be measured by counting the number of these quantized pulses coming out in one train through the gate circuit.

The number counted by the counting tubes for 3 digits are classified by the sorting circuit consisting of ' or gate ' of germanium diodes and ' and gates ' of heptodes, and distributed among the 20 writing circuits of the frequencies in each class.

At the writing circuit to which the output from the sorting circuit is sent, the frequency counter is operated by the trigger pulse which is generated at the last edge of the positive interval of the signal square wave. The frequency counter consists of a counting tube and an electromagnetic counter, and is able to count frequencies up to 5 digits in total.

The range of the period from 0.05 sec. to 2.5 sec. is divided into 20 classes, whose interval is taken as constant in the logarithmic scale, as shown in Table 2.1. In the table representative periods of each class mean are also shown for convenience' sake of actual usage.

2.3

In the design of our instrument, special considerations were paid to obtain promptness and stability of action, and the magnetic recording system was adopted for the recording of the original vibrations and digital system for the calculation mechanism.

To record vibrations, rectangular pulses are pulse-width-modulated ( PWM ) by the output signal from the transducer having the proper period of 1.0 sec., and then recorded on a magnetic tape. The repetition frequency of the pulse and the recording speed of the magnetic tape are 400 pps and 19 cm/sec respectively. The block diagram of the whole apparatus is shown in Fig. 2.1.

Fig. 2.2 illustrates the block diagram of the analyser, and Photo. 2.1 shows its appearance.

This is a brief outline of the principal operations of our analyser. An analyser for voice based on the similar principle has already been made (4). But the frequency band aimed at in our analyser is much lower than the voice-analyser, and classification system has to be made more elaborate and we had many difficulties in design and construction.

Some example of the frequency distributions of the periods of microtremors measured in structures and on the ground by using this analyser are shown in Figs. 2.3 and 2.4.

2.4

Completion of this analyser shortened the time required for the analysis of the frequency-period relationships to one-tenth of that for previous manual operations. And at the same time, personal errors inevitably accompanying manual work have been able to be eliminated. At present this analyser is conveniently used chiefly for the elucidation of period characteristics of the ground and the proper period of structures through the measurement of the microtremors.

The writer wishes to express his deep thanks to Dr. K. Kanai for his kind guidance in this work.

## 3 Automatic Correlator By Etsuzo Shima.

To study the earthquake vibration of a structure up to its failure, it is necessary to treat the structure as a non-linear system. But our present knowledge on the characteristics of the structural materials and the pertinent theory of vibrations of such a system in such a state of high strain is too meagre to warrant adequate solution of the problem in question. Since our primary object of study in earthquake engineering is to prevent the breakage of the structure, the modes and characteristics of structural vibrations in the linear stage are no less important, and constitute indispensable premises for the non-linear theory. It is wellknown that the response of a constant parameter linear system for an arbitrary disturbance is to be obtained by the Fourier's double integral or a convolution integral, provided we know the frequency or impulse response functions of the system.

To know these vibration characteristics, experimental approaches have been made, but being too elaborate as they are, more feasible approaches have been sought and found in the analysis of the responses of the structure to irregular natural disturbances as microtremors due to artificial and other causes. Recent progress in the theory and techniques of communication made it possible to solve the problem very easily. The most powerful weapons found in the communication theory are the harmonic analysers and correlators. The period distribution analyser reported in the preceding chapter is another which is somewhat similar to the harmonic analyser. The correlators or the instruments to calculate correlation functions play very important roles in these fields and promise a very useful application in the vibration theory. In view of these facts we constructed a model of an automatic correlator and used it for the analyses of vibrations of civil engineering structures and grounds for the same purpose. In the following a brief explanation of the theory, construction and applications of the correlator will be given.

## 3.1 Theoretical Background

It is well-known that the output $y(t)$ of a constant parameter linear system for the input $x(t)$ is given by

$$y(t) = \int_0^\infty h(\tau)\ x(t-\tau)\ d\tau \tag{3.1}$$

or

$$y(t) = \frac{1}{2\pi}\int_{-\infty}^{\infty} H(\omega)\ d\omega \int_{-\infty}^{\infty} X(\tau)\ e^{j\omega(t-\tau)}\ d\tau, \tag{3.2}$$

where $h(t)$ and $H(\omega)$ are impulse and frequency response functions respectively, and in themselves constitute a Fourier transform pair, that is

$$H(\omega) = \int_0^\infty h(\tau)\ e^{-j\omega\tau}\ d\tau, \tag{3.3}$$

and

$$h(t) = \frac{1}{2\pi}\int_{-\infty}^{\infty} H(\omega)\ e^{j\omega t}\ d\omega, \tag{3.4}$$

Now our present problem is to find $h(t)$ and $H(\omega)$ of the structure, and the simplest approach to it is the experimental application of an impulse $x(t)=x_0\,\delta(t)$ ( $\delta(t)$: $\delta$-function) or a simple harmonic force $x(t) = x_0\, e^{j\omega t}$ to the input. But the response $y(t)$ to the most irregular stationary ergodic random process $x(t)$ can also yield a very important information of the system if properly analysed, as will be shown below.

It has been proved that the power spectral density functions $W_{11}(\omega)$, $W_{22}(\omega)$ and $W_{12}(\omega)$ of the input and output are related each others through the frequency response function $H(\omega)$ of the system by the following formulae

$$W_{22}(\omega) = |H(\omega)|^2\ W_{11}(\omega), \tag{3.5}$$

and

$$W_{12}(\omega) = H(\omega)\ W_{11}(\omega), \tag{3.6}$$

while the $W(\omega)$s are the Fourier transforms

$$W_{ij}(\omega) = \int_{-\infty}^{\infty} \varphi_{ij}(\tau)\ e^{-j\omega\tau}\, d\tau \tag{3.7}$$

of the auto- or cross-correlation functions

$$\varphi_{11}(\tau) = \frac{1}{2T}\int_{-T}^{T} x(t)\ x(t+\tau)\ dt, \tag{3.8}$$

$$\varphi_{22}(\tau) = \frac{1}{2T}\int_{-T}^{T} y(t)\ y(t+\tau)\ dt, \tag{3.9}$$

and

$$\varphi_{12}(\tau) = \frac{1}{2T}\int_{-T}^{T} x(t)\ y(t+\tau)\ dt \tag{3.10}$$

respectively. We can therefore know the frequency response function of the system $H(\omega)$ by the equations (3.5) and (3.6) from the correlation functions (3.8), (3.9) and (3.10) through the Fourier transformation (3.7).

As the inverse Fouriner transform of (3.7) is

$$\varphi_{ij}(t) = \frac{1}{2\pi}\int_{-\infty}^{\infty} W_{ij}(\omega)\ e^{j\omega t}\, d\omega, \tag{3.11}$$

we have

$$\varphi_{12}(\tau) = \frac{1}{2\pi}\int_{-\infty}^{\infty} H(\omega)\ W_{11}(\omega)\ e^{j\omega\tau}\, d\omega, \tag{3.12}$$

and

$$\varphi_{22}(\tau) = \frac{1}{2\pi}\int_{-\infty}^{\infty} |H(\omega)|^2\ W_{11}(\omega)\ e^{j\omega\tau}\, d\omega, \tag{3.13}$$

from which we can easily deduce the following formulas, when the input is white noise, that is $W_{11}(\omega) = \text{const.} = C$.

$$\varphi_{12}(\tau) = \frac{C}{2\pi}\int_{-\infty}^{\infty} H(\omega)\ e^{j\omega\tau}\, d\omega = C\ h(\tau), \tag{3.14}$$

and

$$\varphi_{22}(\tau) = \frac{C}{2\pi}\int_{-\infty}^{\infty} H(\omega)\ H^*(\omega)\ e^{j\omega\tau}\, d\omega = C\int_{-\infty}^{\infty} h(t)\ h(t+\tau)\ dt$$
$$= C\ \varphi_{hh}(\tau). \tag{3.15}$$

In the above equation, $H^*(\omega)$ denotes the conjugate complex of $H(\omega)$.

It can be shown when

$$h(t) = A\ e^{-\varepsilon t}\sin\sqrt{n^2-\varepsilon^2}\,t \qquad 0 \leqq t \tag{3.16}$$
$$= 0 \qquad 0 > t$$

that

$$\varphi_{hh}(\tau) = \frac{A^2}{4n^2\varepsilon}\quad e^{-\varepsilon\tau}\ \cos(\sqrt{n^2-\varepsilon^2}\,\tau - \theta), \tag{3.17}$$
$$\tan\theta = \varepsilon/n\ .$$

It will be worth noting that the auto-correlation function of the output or the cross-correlation function of the input and output of the linear system responding to the input white noise is by itself the free oscillation of the system, so that we can easily determine the proper period and the damping of the linear system from $\varphi_{22}(\tau)$ or $\varphi_{12}(\tau)$ easily.

### 3.2 Principle of Construction

To calculate the correlation functions defined by the equations (3.8), (3.9) and (3.10), it is necessary to use values of f(t) and g(t) at different times repeatedly. It is therefore convenient to have these values memorized, so that they may be easily recalled.

To comply with the requirements we used electric signals of analogue type for f(t) and g(t), and adopted the magnetic recording method for the electric signals. Considering the high fidelity in the amplification and recording as well as feasibility in the calculation of the products and integrals involved in the correlation functions, the electric signals were pulse-width modulated and used in the calculation as such for one of the f(t) and g(t) while the other being demodulated back to the original analogue form.

Since four values f(t), g(t), f(t+τ) and g(t+τ) are involved in the calculations for $0 \leq \tau$, and magnetic heads for recording and reproducing are finite in their magnitudes, these four values are to be recorded simultaneously in separate tracks on a single tape. We therefore used a tape $\frac{1}{2}$ inch wide, and placed two heads of f(t) and g(t) parallel at a position, and the others for f(t+τ) and g(t+τ) also parallel at a different position.

By changing the length of the tape lying between these pairs of heads little by little in the reproducing process, we can obtain (f(t) or g(t) and f(t+τ) or g(t+τ) of variable τ simultaneously, and the requirement for τ that $o \leq \tau$ is thus secured.

The multiplication of say f(t) and g(t+τ) is made by chopping the demodulated signal g(t+τ) by the pulse width modulated signal of f(t), so that we can have trapezoidal pulse, repeating according to the sampling rate of the pulse width modulation. As the height and width of this pulse is proportional to the g(t+τ) and f(t) respectively, the electric charge transported by this impulse is proportional to the product f(t)· g(t+τ). We can therefore have a point of the correlation function $\varphi_{12}(\tau)$ by integrating the charge of these impulses. This integration is made by means of a condenser.

Our analyser is based on the above principle, and is so made as to perform these calculations automatically, and record the integral, say

$$\int_0^t f(t)\; g(t+\tau)\; dt = \varphi(t,\tau)$$

automatically up to $t = T-\tau$, and to stop at the end and to return to the initial zero position. It then renews its function after increasing the value of τ by a prescribed amount. All these processes are repeated automatically so that we can have the desired correlation function by drawing an envelope of the recorded $\varphi(t,\tau)$ curves.

## 3.3 Actual Construction

The photograph of our apparatus is shown in Photo. 3.1, and its block diagram in Fig. 3.1.

It consists of four units, a) memory unit, b) delay time controller, c) reproducing and calculating unit and d) recorder.

Specifications are as follows:

1) Input signal : 0.5 V (p-p) , 0-20 cps.

2) Input resistance : 5 KΩ.

3) Demodulated output : 1 V (p-p), 0 – 100 cps.

4) Output resistance : 5 KΩ.

5) Magnetic tape : ½ inch wide, 3m long endlessly pasted.

6) Tape speed : 8 cm/sec for recording, 40 cm/sec in reproducing.

7) Power consumption : about 100 watts.

Now let us explain in a little more detail each of the units of our apparatus respectively.

a) Memory Unit

The input signals are amplified by the transistorized DC preamplifier and are modulated by the pulse width modulation system. The pulse width modulated signals are derived easily by changing the slicing level of the saw-tooth waves in proportion to the input signal. The saw-tooth wave generator is contained in this unit, and the repetition frequency of the waves (which we call "sampling rate") is 120 times per second. The modulated signals are amplified once more and fed directly to the magnetic tape recorder. To comply with the above requirements, two pairs of same signals of f(t) and g(t) are recorded on the tape at different positions on the tape as shown in Fig. 3.1. So, four tracks are recorded on the tape simultaneously.

b) Delay Time Control Mechanism

The delay time "$\tau$" between the two time functions, is obtained by changing the length of the tape lying between the fixed heads.
This operation is accomplished as stated bellow (see Fig. 3.2).

i) a piece of tin-foil, 1cm wide and 3.5cm long, which is sticked on the endless tape, passes by the contactor 1, and make a circuit, by which

ii) a contact signal is sent to the relay, to stop the driving the magnetic tape.

iii) At the same time, a motor to shift the movable guide roller down by a prescribed amount is made to work for a moment. By this operation, the length of the tape between the two fixed heads is increased.

iv) After completing this action, the circuit to drive the tape is made.

v) Then the tin-foil contacts with the contactor 2, and the next calculation is started.

Thus, the whole cycle of calculating $\varphi(\tau)$ is repeated automatically. And at last the movable guide roller slides down the whole length of the delay time scale, when a contact maker breaks the power circuit, and the whole function of the correlator is stopped.

In our apparatus, available delay time increments at a time are 1/40sec., 1/80sec. and 1/160sec. respectively. We may select a suitable one of these increments for the frequency characteristics of the input signals. And, if it is necessary, we may also select arbitrary delay times by the manual shifting of the guide roller.

c) Reproducing and calculating unit.

In the calculation process, we first reproduce two of the four recorded signals from the tape, depending on the problem. For instance, if we want to calculate an auto-correlation function, we reproduce $f(t)$ and $f(t+\tau)$. or $g(t)$ and $g(t+\tau)$. In the case of a cross-correlation function we reproduce $f(t)$ and $g(t+\tau)$ or $f(t+\tau)$ and $g(t)$. Because of the differential characteristics of the reproducing heads, the pulse position modulated signals are derived from the tape as the outputs. And we change them again to the pulse width modulated signals for convenience sake in the latter calculations.

Now the multiplication of the two functions is explained. This is done as follows: (As an example, we will explain the case of cross-correlation function of $f(t)$ and $g(t)$.)

i) One of the signals, say $g(t+\tau)$, is demodulated by the low pass filter.
ii) And chopping this by the other pulse width modulated signal, we obtain a series of trapezoidal pulses whose height and width are proportional to $g(t+\tau)$ and $f(t)$ respectively.
iii) We sent this waves through the low pass filter.
By the output current of this filter, we charge the condenser during one cycle of the calculation.

Now the voltage across the condenser is proportional to a value of the correlation function between $f(t)$ and $g(t+\tau)$ for a given $\tau$. This voltage is amplified and the result is fed to the recorder.

In our apparatus, KR-type penwriter of YEW is used as a recorder. At every end of the calculation cycles the tape is stopped and to prepare for the next cycle, a condenser is clamped by a constant voltage and the pen swings back quickly to the zero position. The necessary time of one calculation cycle, is about 7.5 seconds. In this way the calculations are repeated over and over again untill the delay time "$\tau$" between the two functions becomes large enough. The results of these calculations are recorded with constant intervals on a sheet of paper driven very slowly, so that the correlation function is easily given as the envelope of these curves.

Theoretically, the value of the auto-correlation function should be maximum at the zero delay time. But from the practical point of view, as we use the low pass filter, the time lag of the physically realizable low pass filter should be considered. In our apparatus this time lag is about 6.5 milli-seconds. And we may say that this value is constant in the frequency range of interest.

At the end of this article, we had better to note that, because the circuits of this apparatus are all transistorized, the whole equipment is made smaller and lighter than any other which has hitherto been made.

### 3.4 Calculated Examples

In Fig. 3.3 and 3.4, the examples worked out are given. Fig. 3.3a and 3.3b are the examples of auto-correlation functions, where the input signals are derived from the very low sine wave generator (Oscillator).

These examples will show that the correlator works satisfactorily. To test the stability of the function of our correlator, we calculated at different times from the same record the auto-correlation functions of the microtremors observed at the 2nd floor of the Earthquake Research Institute. The results which are shown in Fig. 3.4a and 3.4b are exactly the same, and this shows that the correlator works very stably. Fig. 3.5a through 3.5d are examples to show the validity of the above mentioned equations, that we can obtain free vibrations of structures by our apparatus from microtremor observations.

3.5 Acknowledgements

The author expresses his hearty thanks to Professor Hiroshi Kawasumi who gave him valuable discussion and encouragement. The author's thanks are also due to the staff of Sony Corporation who gave him technical assistance and many facilities. The author wishes to acknowledge the assistance of the Ministry of Education and of Construction in providing funds to enable the apparatus to be constructed. Without their collaboration and aids this correlator would not have been brought into being.

Bibliography

2. K. Kanai, T. Tanaka and K. Osada, "Measurement of the Microtremor. I", Bull. Eqrthq. Res. Inst., 32(1954), 199.

K. Kanai and T. Tanaka, "A Measuring Instrument for Brief Measurement of Natural Period of Building ", Building Engineering, Edited by Building Research Institute, No. 34(1954), 39.

G. Nishimura and M. Suzuki, " Method for Obtaining Predominant Period of Vibration ", Vibration, Edited by Vibration Conversation, 2(1948), 88.

T. Sakai and S. Inoue, " An Analyzing Equipment for Zero-crossing Interval and its Applications to Speech Analyses ", The Journal of the Institute of Electrical Communication Engineers of Japan, 39(1956), 404.

3. S. Goldman, " Information Theory ", Prentice-Hall, Inc. New York, 1953.

Y. W. Lee, " Application of Statistical Methods to Communication Problems ", M. I. T. Technical Report, 181(1950).

J. S. Bendat, " Principles and Applications of Random Noise Theory ", John Wiley & Sons, Inc., New York. (1958).

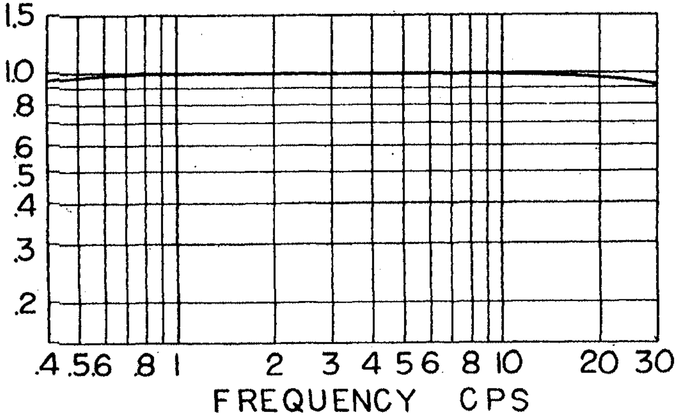



**Fig. 1.1** Frequency Characteristics of DK-3CH and DK-3CV, Accelerometers.

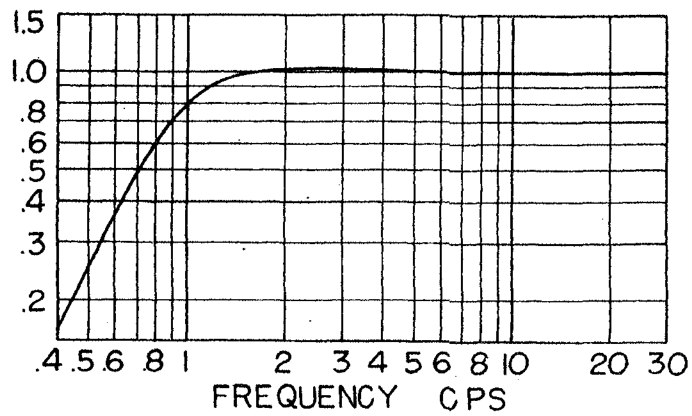



**Fig. 1.2** Frequency Characteristics of DK-1CH and DK-1CV, Seismometers.

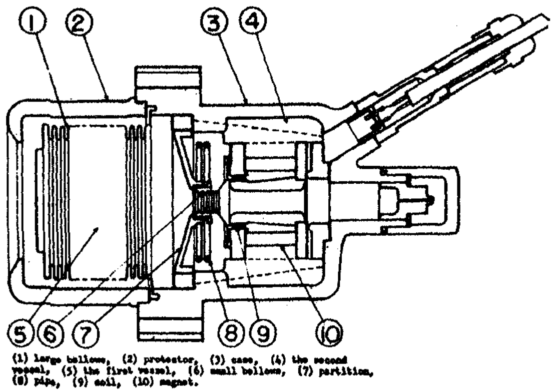



**Fig. 1.3** Cross Section of Hydrodynamic Pressure Gauge.

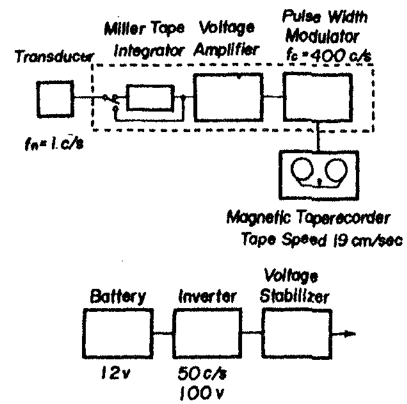



**Fig. 2.1** Block diagram showing the constitution of the measuring equipment.

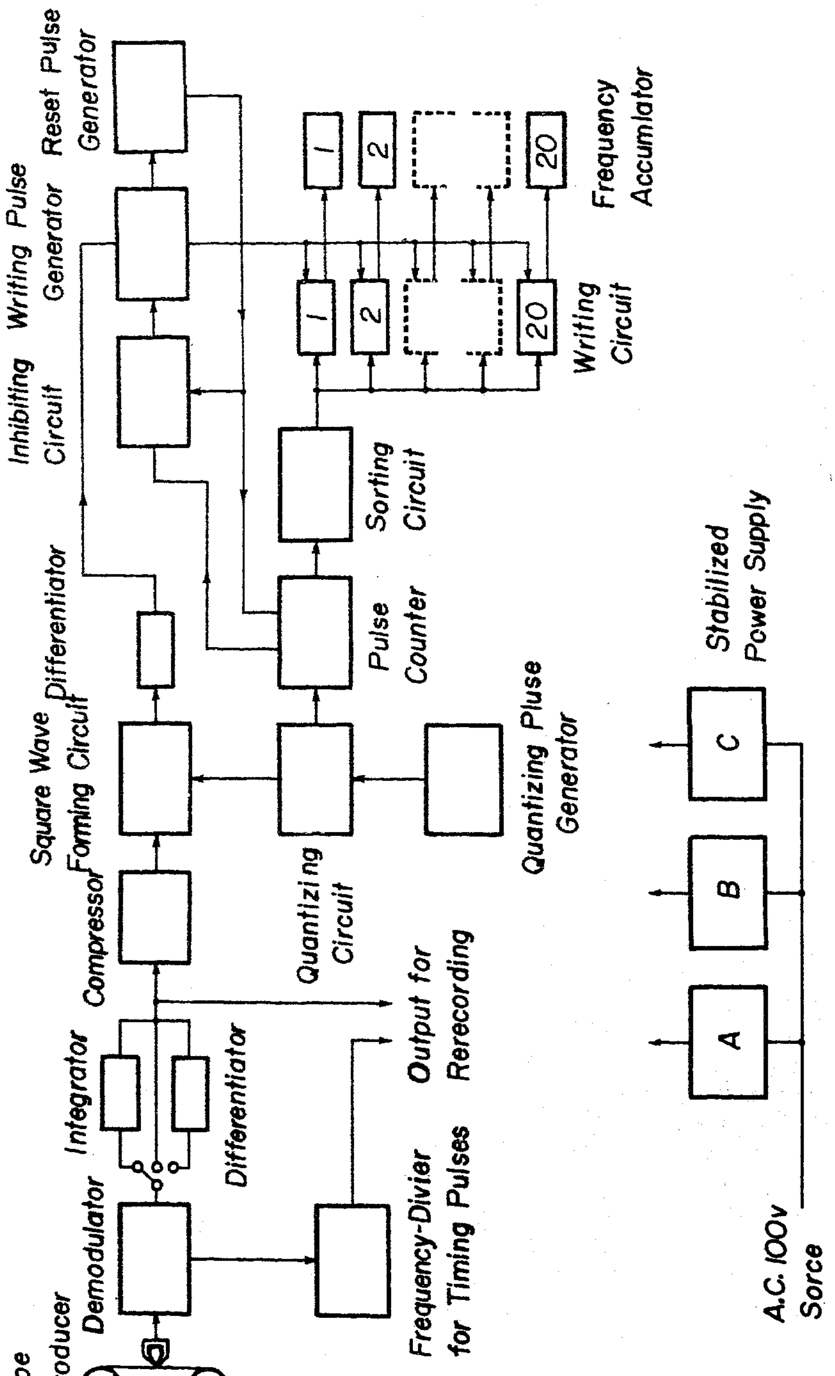



Fig. 2.2 Block diagram showing the constitution of period distribution analyser.

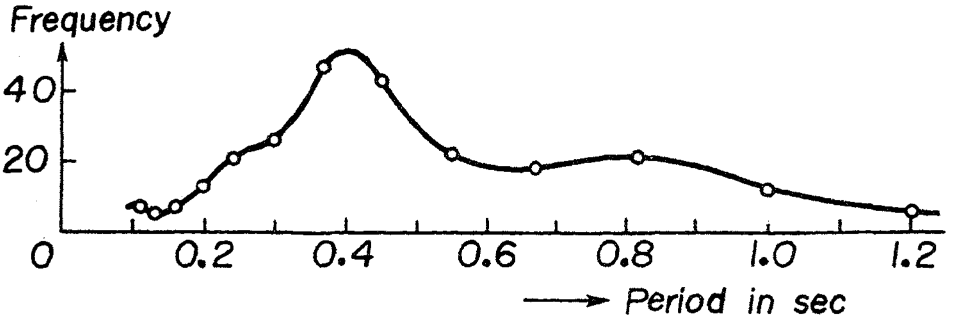



Fig. 2.3 An example of result of analysis of period-frequency relationships in micro-tremors observed on ground.

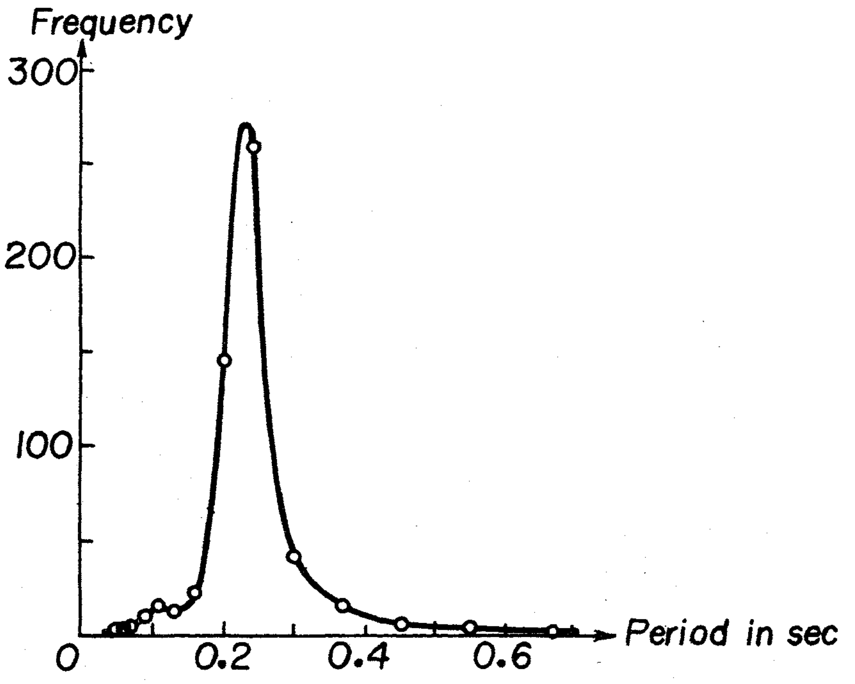



Fig. 2.4 An example of result of analysis of period-frequency relationships in vibrations at the top of a building due to micro-tremors at ground.

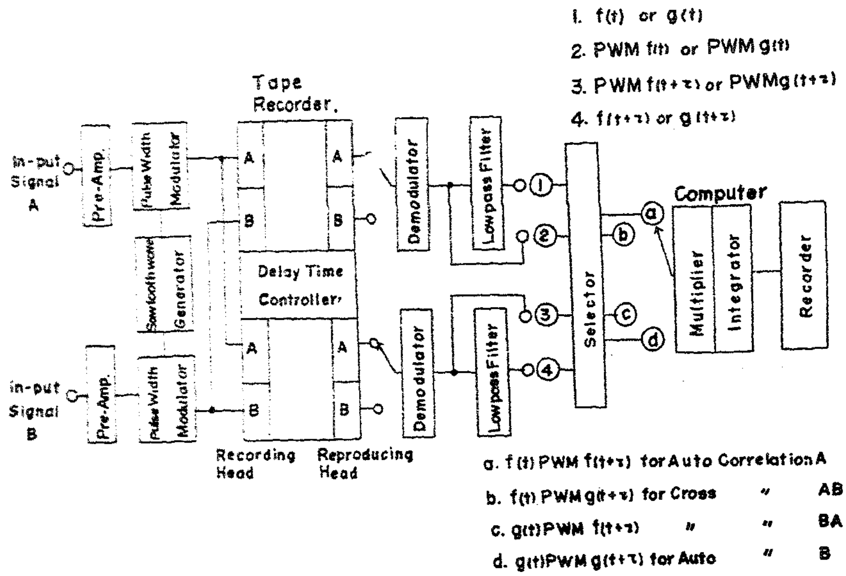



Fig. 3.1 Block diagram of the automatic correlator.

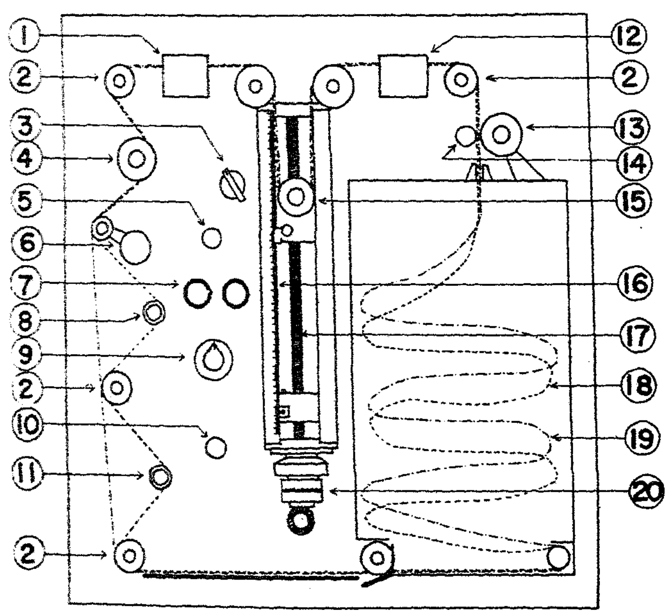
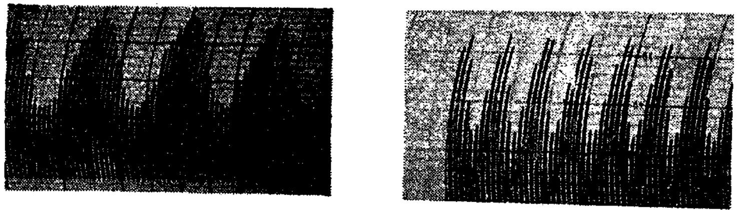
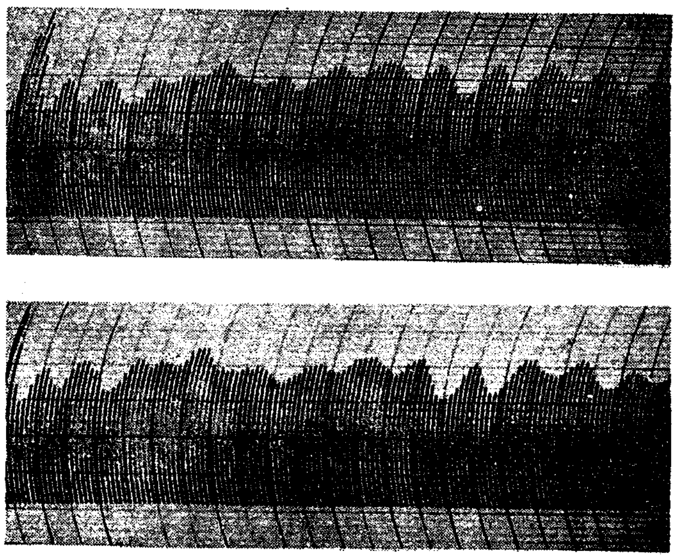


Fig. 3.2 Schematic view of the memory unit. (1) Recording head A, (2) guide roller, (3) tape speed selector, (4) fly wheel, (5) pilot lamp, (6) tension arm, (7) push buttons. (8) contactor 2, (9) delay time selector, (10) transfer switch, (11) contactor 1, (12) recording head B, (13) pinch roller, (14) capstan, (15) delay time controlling guide roller, (16) delay time scale, (17) feed screw, (18) tape (reproducing stage), (19) tape (recording stage), (20) adjuster.



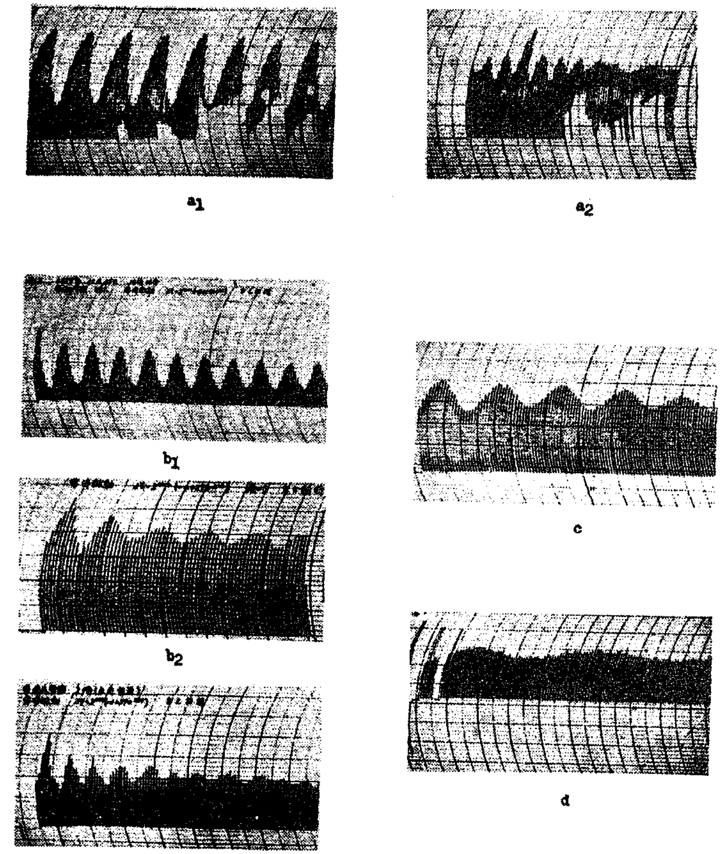
a b

Fig. 3.3 Example of calculated auto-correlation functions of sine wave of (a) 2cps, ($\Delta\tau$ = 0.027 sec.), (b) 20cps, ($\Delta\tau$ = 0.0068 sec.)



t

Fig. 3.4 Auto-correlation functions of the natural minute irregular motions observed at the second floor of the Earthquake Research Institute as calculated at different times from the same record. ($\Delta\tau$ = 0.027 sec.)



$a_1$ $a_2$ $b_1$ $b_2$ $b_3$ c d

Fig. 3.5 Auto-correlation functions of the natural minute irregular motions of structures. The observations were made ($a_1$),($a_2$) at the top of an arch-dam; ($b_1$) on the ground, ($b_2$) on the second floor of a wooden building, ($b_3$) on the ground floor of a RC building at the margin of up-town Tokyo; (c) on the roof of a 7-storied framed building; (d) at the 130m level of a TV tower. (a):$\Delta\tau$ = 0.011 sec., (b),(c),(d):$\Delta\tau$ = 0.027 sec.

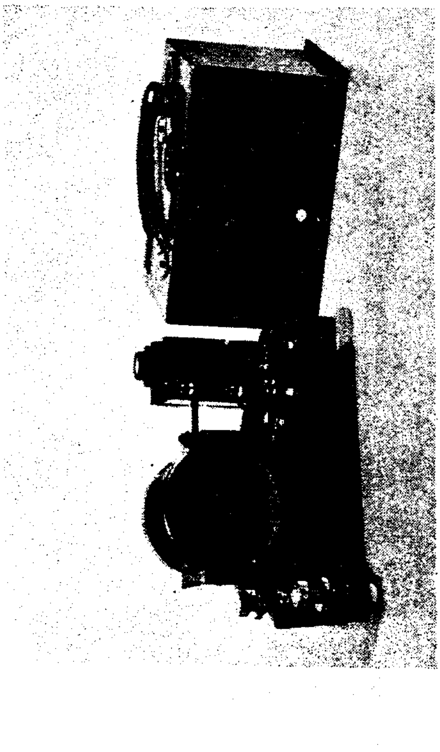


Photo. 1.1a DK-3CH.

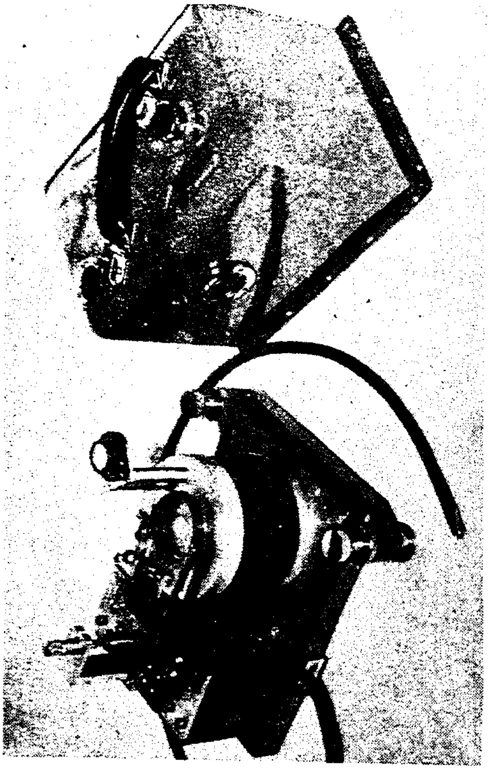


Photo. 1.1b DK-3CV.

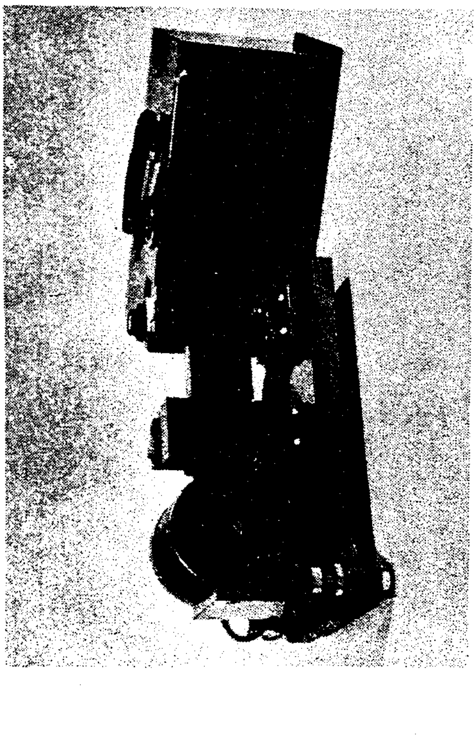


Photo. 1.2a DK-1CH.

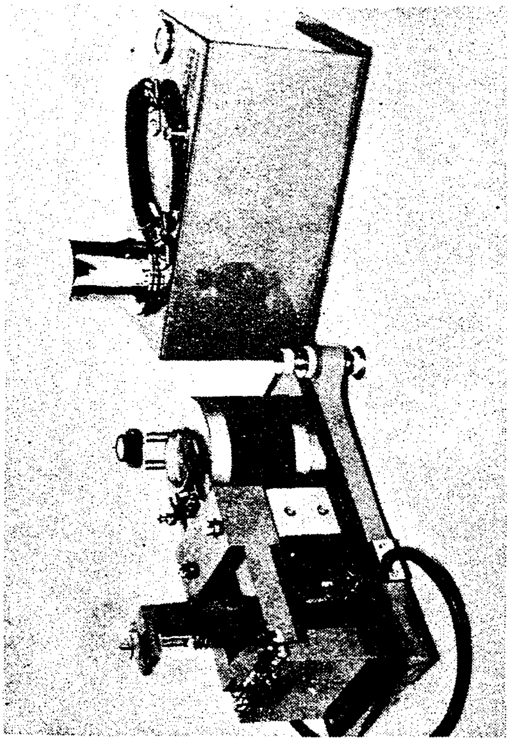


Photo. 1.2b DK-1CV.

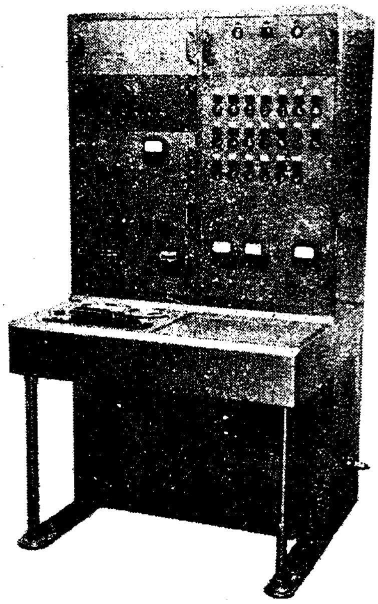


Photo. 2.1 Appearance of period distribution analyser.

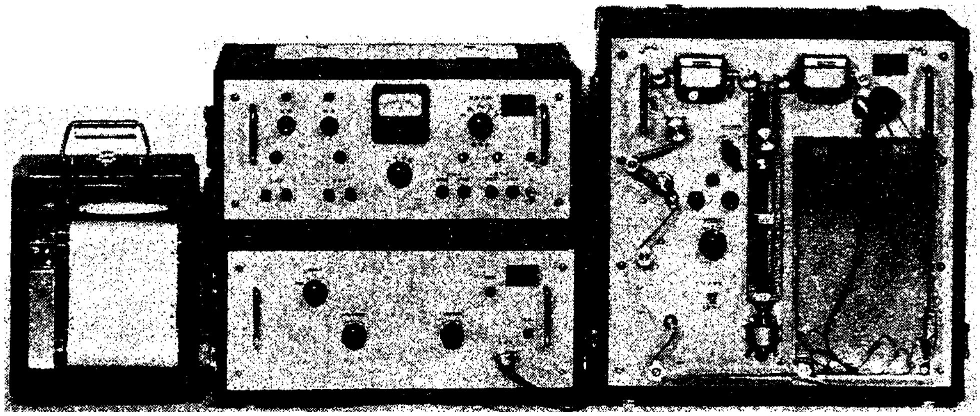


Photo. 3.1 The automatic correlator.

Table 1.1 The Constants of Seismometers

| Type of Seismometer | | DK-1CH | DK-1CV | DK-3CH | DK-3CV |
|---|---|---|---|---|---|
| Component | | Hor. | Vert. | Hor. | Vert. |
| K | $gr \cdot cm^2$ | $1.84\times10^5$ | $1.84\times10^5$ | 5800 | 5800 |
| M | gr | 2400 | 2200 | 440 | 300 |
| H | cm | 7.3 | 8.2 | 2.2 | 3.2 |
| Natural Freq. | cps | 1.0 | 1.0 | 3.0 | 3.0 |
| Sensi-tivity | volt/kine | 0.27 | 0.27 | | |
| | $\mu A$/gal | | | 15 | 15 |
| Coil Resist. | $\Omega$ | 10 | 10 | 121 | 121 |

Table 2.1 The Classification of Period

| No. | Representative Period (sec) | Range of Period (sec) |
|---|---|---|
| 1 | 0.05 | 0.05 |
| 2 | 0.06 | 0.06 |
| 3 | 0.07 | 0.07 |
| 4 | 0.09 | 0.08-0.09 |
| 5 | 0.11 | 0.10-0.11 |
| 6 | 0.13 | 0.12-0.14 |
| 7 | 0.16 | 0.15-0.17 |
| 8 | 0.20 | 0.18-0.21 |
| 9 | 0.24 | 0.22-0.26 |
| 10 | 0.30 | 0.27-0.31 |
| 11 | 0.37 | 0.32-0.39 |
| 12 | 0.45 | 0.40-0.49 |
| 13 | 0.55 | 0.50-0.59 |
| 14 | 0.67 | 0.60-0.74 |
| 15 | 0.82 | 0.75-0.89 |
| 16 | 1.00 | 0.90-1.09 |
| 17 | 1.20 | 1.10-1.29 |
| 18 | 1.45 | 1.30-1.59 |
| 19 | 1.80 | 1.60-1.99 |
| 20 | 2.25 | 2.00-2.49 |