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48. *Period Distribution Analyser for Irregular Motions.*

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1. Introduction.

For the analysis of the records of irregular motions such as earthquake, microtremors and noise, the distribution of zero-crossing intervals (half periods) has been used broadly and to advantage. We have also used it in analysing microtremors of the ground and building vibrations caused by such tremors. This method of elucidating the period characteristics of ground and structural vibrations is expedient and more feasible than other methods of analysis. Nevertheless, to read off the periods by means of a scale directly from a record is very laborious and is liable to observational errors. On the other hand, with the increasing usefulness of microtremor measurement in the field of engineering seismology, more efficient means of analysis has become necessary.

In order to meet the above requirement, a period distribution analyser was devised and constructed several years ago. In the following pages a brief explanation of the principle as well as the construction of the analyser is given.

The magnetic recording type microtremometer constructed as a recording part of the analyser has already been reported in the previous bulletin[1].

2. Classification of periods.

The usual method of drawing the frequency-period diagram of vibration is as follows:

The zero-crossing intervals of all the waves are read from a record of vibration. The time interval thus read is doubled and it is considered to be the period corresponding to the half wave. The total number of zero-crossings (N_i) contained in the period range from T_i to T_{i+1} is represented by the center period (T_i') of the range, where T_i is a period

1) T. TANAKA, *Bull. Earthq. Res. Inst.*, **40** (1962), 533.

taken arbitrarily and T_{i+1} is the period larger than T_i by ΔT. Then, taking T_i' on the abscissa and N_i of each period range on the ordinate, the curve of frequency-period is drawn.

Using the method of analysis, M. Ishimoto[2] has determined the predominant periods of ground at various places in Tokyo and Yokohama from the observations of earthquakes, and T. Saita and M. Suzuki[3] also applied it for finding the natural period of buildings. In their analyses the value of ΔT was taken as constant, i.e., 0.035 sec and 0.026 sec. In the earlier stages of our microtremor study, the same method of period classification ($\Delta T=0.020$ sec) was also used, because it seemed to be suitable for comparing the predominant period of the ground determined by M. Ishimoto with that obtained from the microtremor measurement at the same spot. However, such a method for period classification is not always suitable in cases where the vibration period extends over a wide range or when the frequency-period curve has several peaks. That is, the frequency-period curve is liable to predominance at short-period range. In other words, the predominant period is considerably hard to find in cases where it exists in a comparatively long-period range.

To overcome these disadvantages a more reasonable method for period classification was proposed by G. Nishimura and M. Suzuki[4]. In their method, period interval (ΔT_i) is taken as constant in the logarithmic scale.

Now, let us consider a geometrical series expressed by

$$T_i = T_0 \gamma^i \,, \quad [\gamma > 1,\ i = -h, \cdots -1,\ 0,\ 1, \cdots,\ h] \,,$$

where T_0 is an arbitrary period and γ a constant. Consequently, the interval between ith and $i+1$th period ΔT_i and the center period T_i' are given by

$$\Delta T_i = T_0 \gamma^i (\gamma - 1)$$

and

$$T_i' = \frac{T_0 \gamma^i (\gamma + 1)}{2} \,.$$

2) M. ISHIMOTO, *Bull. Earthq. Res. Inst.*, **10** (1932), 171: **12** (1934), 234: **13** (1935), 592: **14** (1936), 240.

3) T. SAITA and M. SUZUKI, *Bull. Earthq. Res. Inst.*, **14** (1936), 104.

4) G. NISHIMURA and M. SUZUKI, *Vibration*, **2** (1948), 88 (in Japanese).

Therefore,

$$\frac{\Delta T_i}{T_i'} = \frac{2(\gamma-1)}{\gamma+1} .$$

If we put $\Delta T_i/T_i'=\alpha$, then γ can be written as

$$\gamma = \frac{2+\alpha}{2-\alpha} .$$

α is a constant which governs the resolvability of period in the analysis. Namely, the larger the value, the lesser the unevenness of the curve of frequency-period diagram becomes. The latter method has been in use since about 1959 in our microtremor analysis instead of the former one.

It has been pointed out by K. Kanai that in the case where the frequency-period curve has many small peaks, the period corresponding to the respective peak has little physical meaning, so that the use of too small a value of α is considered undesirable for the analysis of earthquakes and microtremors. Taking this into consideration, we have adopted $\alpha=0.2$. In Table 1 the calculated values of T_i, T_i' and ΔT_i in the case of

Table 1.

i	T_i (sec)	T_i' (sec)	ΔT_i (sec)
0	0.020	0.022	0.004
1	0.024	0.027	0.005
2	0.030	0.033	0.007
3	0.037	0.041	0.008
4	0.045	0.050	0.010
5	0.055	0.061	0.012
6	0.067	0.074	0.015
7	0.082	0.091	0.018
8	0.100	0.111	0.022
9	0.122	0.135	0.027
10	0.149	0.165	0.033
11	0.182	0.202	0.040
12	0.222	0.247	0.049
13	0.272	0.302	0.060
14	0.332	0.369	0.074
15	0.406	0.451	0.090
16	0.496	0.551	0.110
17	0.606	0.674	0.135
18	0.741	0.823	0.165
19	0.905	1.006	0.201
20	1.107	1.230	0.246
21	1.353	1.503	0.300
22	1.653	1.837	0.367
23	2.021	2.245	0.449
24	2.470	2.744	0.549
25	3.018	3.354	0.671

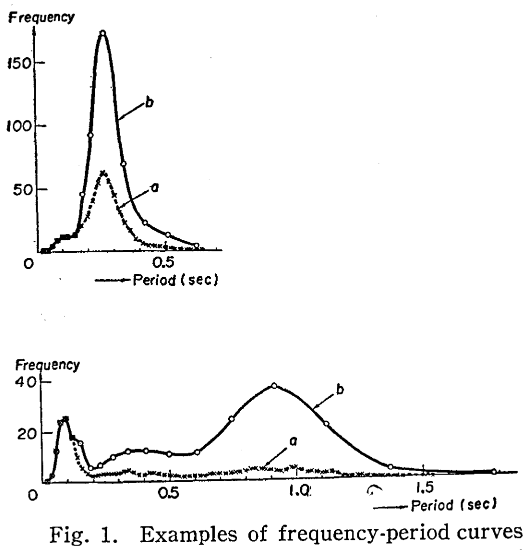

Fig. 1. Examples of frequency-period curves of microtremors obtained by different methods of classification. a; Constant period interval (ΔT $=0.02$ sec). b; Constant period interval in the logarithmic scale ($\alpha=0.2$).

$T_0=0.02$ sec and $\alpha=0.2$ are listed for convenience' sake of actual usage.

The frequency-period curves of the microtremors at different kinds of ground by two methods of period classification are shown in Fig. 1. It will be seen in Fig. 1 that there is no significant difference between the curves in the case of the peak period in the short-period range, while in the case where the comparatively long-period waves predominate, the contrast between them is remarkable. As regards the frequency-period curve having a single peak, the latter classification method, as compared with the former one, gives about 5% larger values in the predominant period and 8~10 times higher peaks in the periods of around 1.0 sec.

In applying the above-mentioned method to the analyser, a slight modification of the theoretical values was made to simplify the mechanism. In the modified classification the range of the period from 0.05 sec to 2.50 sec, which covers almost all the periods contained in microtremor waves, is divided into twenty classes as shown in Table 2. Fig. 2 gives examples of the results obtained by applying the original and modified classifications to the same microtremor record. It may be said from Fig. 2 that the variation between the two curves is worth little consideration in practice.

Table 2. Actual classification of periods in the analyser.

Channel No.	Range of periods (sec)	Represntative period (sec)	No. of pulse count
1	0.05—0.06	0.055	5
2	0.60—0.07	0.065	6
3	0.07—0.08	0.075	7
4	0.08—0.10	0.090	8, 9
5	0.10—0.12	0.110	10, 11
6	0.12—0.15	0.135	12— 14
7	0.15—0.18	0.165	15— 17
8	0.18—0.22	0.200	18— 21
9	0.22—0.27	0.245	22— 26
10	0.27—0.32	0.295	27— 31
11	0.32—0.40	0.360	32— 39
12	0.40—0.50	0.450	40— 49
13	0.50—0.60	0.550	50— 59
14	0.60—0.75	0.675	60— 74
15	0.75—0.90	0.825	75— 89
16	0.90—1.10	1.000	90—109
17	1.10—1.30	1.200	110—129
18	1.30—1.60	1.450	130—159
19	1.60—2.00	1.800	160—199
20	2.00—2.50	2.250	200—249

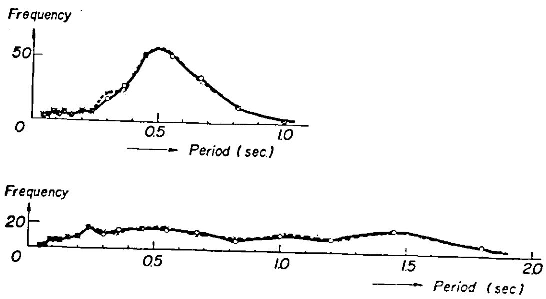

Fig. 2. Examples of frequency-period curves of microtremors obtained by the original (○) and modified (×) classification methods.

3. Principle of operation.

In order to make automatic such procedures in the frequency-period analysis as mentioned above, we constructed a model of an analyser as shown in Fig. 3. For the measurement of time intervals, there are two methods, i. e., the "Analog" and "Digital" methods. The digital method has been employed with a view towards getting stable operation and quick response in the analysis. The block diagram of the automatic analyser is illustrated in Fig. 4, and the blocks drawn with a thick line represent the essential parts of it. The analyser consists of several parts which perform the following operations.

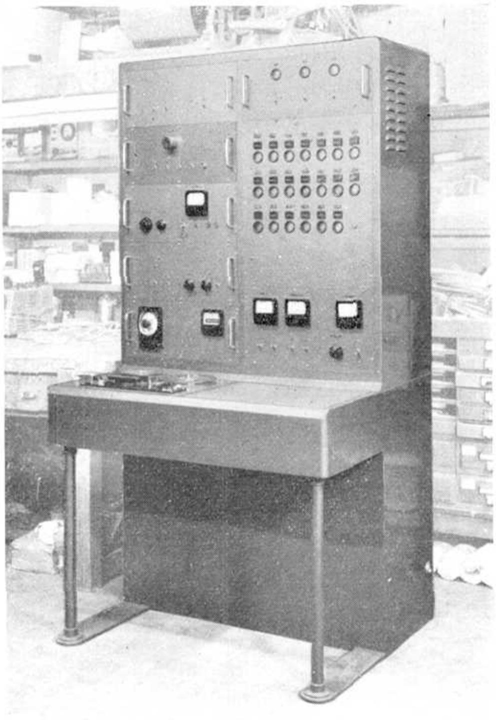

Fig. 3. Period distribution analyser.

The vibration recorded on the magnetic tape by the pulse width modulation (PWM) system is taken out as an electric signal through the tape reader and

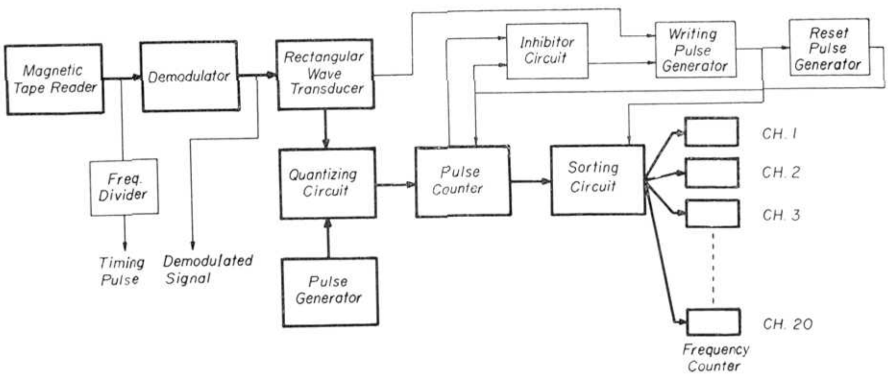

Fig. 4. Block diagram of period distribution analyser.

demodulator. The demodulated signal is sent through the rectangular wave transducer to convert it into a rectangular wave with a constant amplitude, keeping the same period as the original signal. On the other hand, the narrow pulses of 200 cps are produced by a pulse generator based on a crystal-controlled oscillator. These pulses, together with the signal rectangular waves, are applied to the quantizing circuit, which is a sort of "Simultaneous Gate", and the pulse of 200 cps passes through the gate only when the rectangular wave has positive voltage. In this way the quantization of the positive interval (half period) of the signal rectangular wave is accomplished. The time length of each positive interval is measured by counting the number of these quantizing pulses emerging in one train through the gate circuit.

The period of a signal wave T is given from the number of quantizing pulses N and the repetition frequency of the pulse f by

$$T=\frac{2N}{f} .$$

In the analyser, frequency of 200 cps was chosen for the pulse so that the above relationship is expressed very simply as $T=0.01N$. The number of quantizing pulses is obtained by counting circuit for 3 digits and classified into one of the 20 ranges listed in Table 2. At the completion of the count, a signal is sent to the appropriate writing circuit by means of logical connection. When a writing pulse, which is generated at the trailing edge of the individual rectangular wave, is fed to the writing circuit, a count is registered in the proper counting circuit. A separate channel and counting circuit is provided for each of the 20 period ranges. The purpose of the counting circuits is, of course, to register the number of classified pulses in each of the ranges.

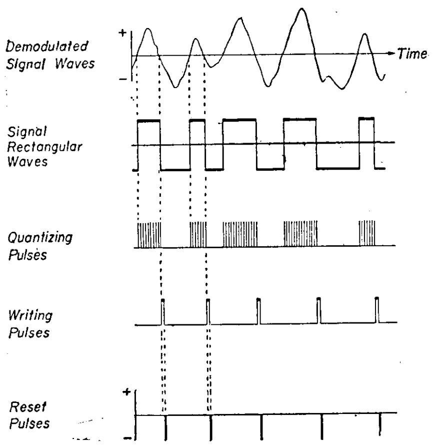

Fig. 5. Waveforms and phase relationship of signals used in the analyser.

After a writing operation is completed and during the negative interval of the rectangular signal, a pulse is applied to reset the quantizing pulse counter for preparing the next operation.

To make the above-mentioned

operations more understandable, the waveforms and the phase relationship of signals used in the analyser are shown in Fig. 5.

The analyser is similar in principle to that for vocal sounds.[5] However, the frequency band aimed at in our device is much lower than the voice-analyser, and the classification method has to be made more elaborate with consequent difficulties in design as well as in construction.

4. Actual construction.

In this analyser, Model 503 SONY Tapecorder is used as a tapereader. The nominal value of the wow and flutter is less than 0.2%. The tape is driven at the same speed (19 cm/sec) when it is recorded. The demodulator circuit employed in the device is of the ordinary kind which consists of a bistable multivibrator and a low-pass filter. The demodulated signal is applied both to the rectangular wave transducer and to a signal level indicator through a cathode-follower amplifier. The level indicator is a rectifier type A. C. voltmeter having a low-pass filter between the rectifier and the meter element, and indicates the mean value of peak voltage of the signal. An attenuator is provided in front of the rectangular wave transducer and enables us to adjust the input signal to the transducer to a certain level.

The demodulated signal can be recorded again on a recording paper by means of the pen-oscillograph, and the necessary time marks for it are obtained by frequency-dividing the differentiated pulses of 400 cps which may be taken out from the playback head when the tape is read. Since a quartz-crystal oscillator having the frequency accuracy of 10^{-5} in normal operation is used for generating the carrier pulse in the modulator,[6] the time marks thus obtained have the same accuracy in frequency. The frequency dividing circuit consists of a chain of special dividers using the gated-beam tube (6BN6). This type of frequecy divider facilitates the actual construction of the circuit. The frequency of 400 cps of the input pulse is stepped down to four frequency steps, 100, 20, 5 and 1 cps, and the timing pulses may be read out from any of these steps.

The conversion of the original signal wave demodulated into the

5) T. SAKAI and S. INOUE, *Jour. Inst. Elect. Commun. Engrs, Japan,* **39** (1956), 404 (in Japanese): *Jour. Acoust. Soc., America,* **32** (1960), 441.

6) *loc. cit.*, 1).

rectangular wave can be realized easily by using the nonlinear circuits. In the device an amplitude compressor of germanium diodes and a four-stage triode limiter with cascaded connection of an overloaded amplifier are used. The demodulated signal is compressed firstly in amplitude by passing through the compressor. Then it is fed to the limiter and the signal rectangular wave is taken out from its output. A switch is installed at the last stage of the circuit to allow measurement of either the positive or the negative zero-crossing time intervals.

It is essential in the quantization of the zero-crossing intervals to use the quantizing pulse with accurate repetition frequency. The pulse generator based on the crystal-controlled oscillator is adopted for this purpose. The square waves of 200 cps are obtained from the 10 KC oscillator by passing through a 25-to-1 frequency divider and a bistable circuit. The output square waves are then fed to a RC differential network with a time constant of 10 μs to obtain narrow pulses.

A simultaneous gate circuit of a gated-beam tube 6BN6 is used as the quantizer. The pulses of 200 cps are applied to the suppressor grid and the signal rectangular wave to the control grid of the tube. Thus the quantizing pulse passes through the gate only when the signal wave has positive sign.

The pulse counting circuit is composed of a three-stage dekatron counter and is capable of counting the number of pulses for 3 digits. Before the quantizing pulses are applied to the counting circuit, they are sent to a monostable multivibrator and are converted into the negative pulses with the voltage of over 100 volts to make sure of the counting operation. The dekatron used is of the type 4CG-10B which can be taken out of the output from any of its ten cathodes.

As has been mentioned, in our analyser, the signal waves in the period range from 0.05 sec to 2.50 sec are classified into the assigned 20 ranges. In practice, this classification is made by a combination of two different types of sorting circuit. The number of 5 to 249 counted by the counting circuit is classified once into 28 ranges by the first sorting circuit consisting of the "or" gates, then the output is classified again into one of 20 ranges through the second sorting circuit consisting of the "and" gates. The first and second sorting circuits are composed of 58 pieces of germanium diodes (1N34 or 1N39) and 24 tubes of heptodes (6BE6), respectively. The schematic diagram of each sorting circuit is shown in Figs. 6 and 7.

For technical reasons some of the outputs from the first sorting

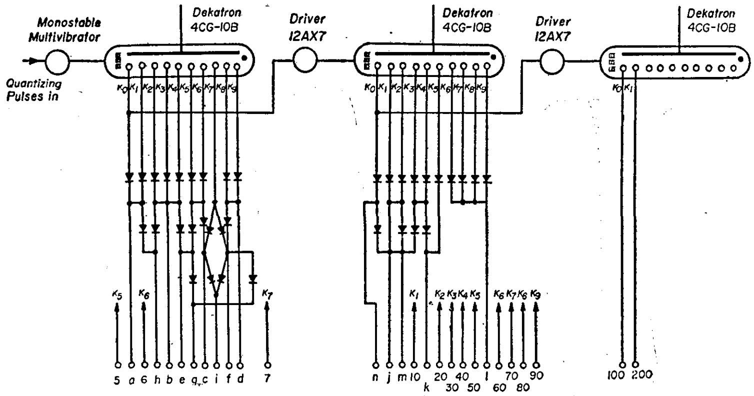

Fig. 6. Schematic diagram of the first sorting circuit.

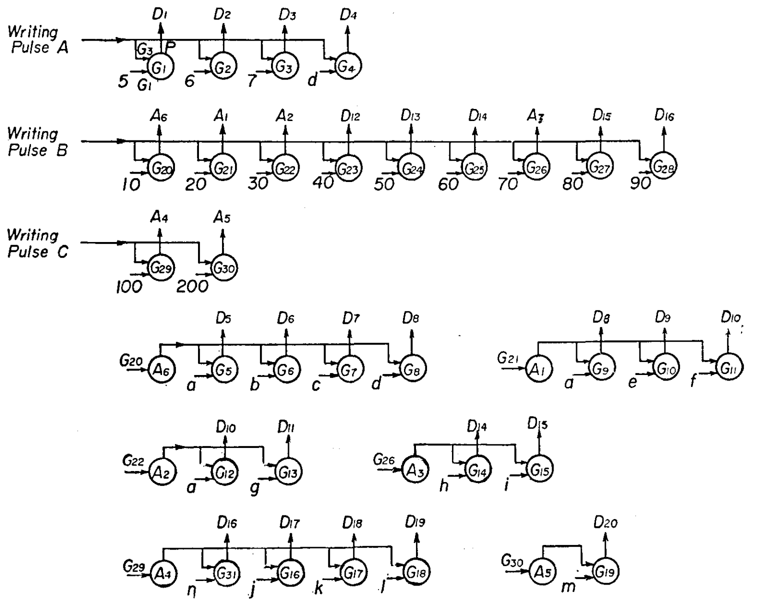

Fig. 7. Schematic diagram of the second sorting and writing circuits. G: Simultaneous gate (6BE6). A: Phase inverter (1/2 6J6). D: Dekatron (4CG-10A).

circuit are gated with writing pulses before the second sorting operation is performed. The writing pulse is a positive rectangular pulse with a dulation of about 1 ms, and is formed from the trailing edge of the individual signal rectangular wave. The writing pulses A, B and C are used respectively for the "and" gate (simultaneous gate) circuits corresponding to 1, 10 and 100 places. The writing pulse C is supplied directly from the writing pulse generator to the proper gate circuits, while the pulses A and B are fed through inhibit gate circuits. The inhibit gate interrupts the feeding of the pulse to the "and" gate circuit when it accepts a carry pulse derived from the quantizing pulse counter. At the completion of the second sorting and the writing operations a pulse is sent out to the proper frequency counting circuit to register a count. If the device had no inhibitor circuit, the count would be registered into two or more counters at the same time.

The frequency counting circuit consists of a dekatron counter (4CG-10A) and a electromechanical impulse register, and is capable of counting frequencies up to a total of 5 digits. The dekatron counter delivers a pulse to its output every time 10 pulses are supplied to its input, but the power of the output is too weak to drive the register, so that a driver (thyratron 2D21) is inserted between the two counters. The impulse register is of the usual type and its maximum capacity is 10^4 counts for one complete cycle.

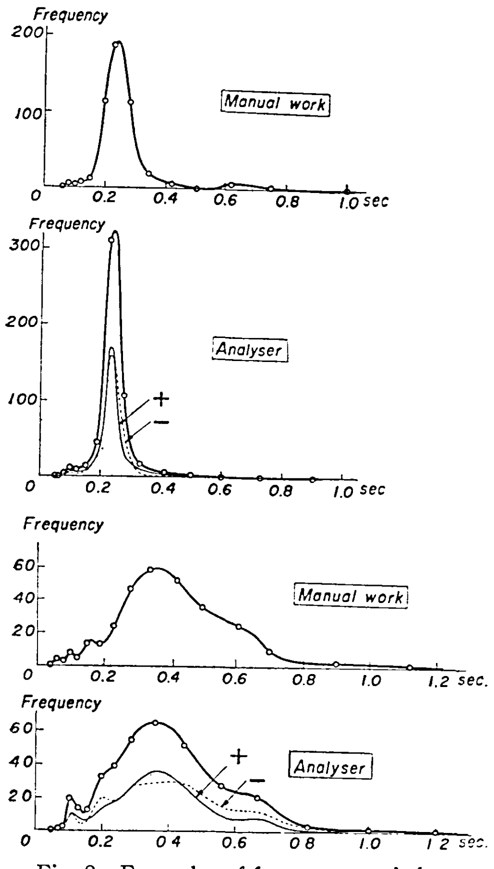

Fig. 8. Examples of frequency-period curves of microtremors analysed by the analyser and manual works.

5. Concluding remarks.

Some examples of the period distributions of microtremors in a building and on the ground obtained by this analyser are shown in Fig. 8. The results from a manual operation are also shown in the same figure for comparing both results. For the manual analysis the reproduced records from the magnetic tape, which have been analysed by the analyser, were used. In the frequency-period diagrams obtained by the analyser, the fine lines indicated with the marks (+) and (−) are the results corresponding to each of the positive and negative intervals of the waves. These examples tell us that the working of the analyser is satisfactory.

The time for the analysis of the frequency-period relationships by the present method is shortened to one-tenth of that by previous manual operations. And, at the same time, personal errors inevitably accompanying manual work are considerably eliminated by this method. At present this analyser is conveniently used chiefly for elucidating the period characteristics of the ground and the natural period of structures through the measurements of microtremors.

In conclusion, the writer wishes to express his sincere thanks to Dr. Kiyoshi Kanai for his cordial direction and advice. He is also grateful to Dr. K. Takeyama and Dr. K. Nakagawa of the Building Research Institute, Ministry of Construction, who made it possible for him to complete this work. The writer's thanks are also due to Mr. T. Asada for his whole-hearted co-operation in the construction of the device. This work has been supported by the funds of the Ministry of Construction.

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48. 周期頻度解析器

地震研究所 田 中 貞 二

地震動や常時微動のような，不規則な振動波形にたいする周期解析の一方法として，振動周期の頻度分布をしらべる方法が古くから使われている．われわれもまた，この方法を常時微動の解析に応用しているが，多数の測定記録を処理する場合には，周期の読取り，分類などにかなりの労力を必要とする．周期頻度解析器は，これらの記録処理を自動化する目的で作られたものである．

この解析器では，0.05 sec から 2.50 sec までの周期範囲の波を，その周期間隔が等比級数をなす20 の群に分類し，一定時間内にそれぞれの群に分類，登算される波数を計数する．周期の測定には，時間の長さを量子化パルスの数におきかえて計測する digital 方式を採用し，また，周期の分類は“or”および“and”ゲート回路の組合せによつて実現されるので，働作はきわめて安定である．