Bulletin of the Disaster Prevention Research Institute, Vol. 15, Part 3, No 100, March, 1966

On the Extensometer of a Variable Capacitor Type

By Torao TANAKA

(Manuscript received January 13, 1966)

Abstract

Descriptions of a newly devised extensometer of a variable capacitor type, and some observational results at Kamigamo and Osakayama Observatories of Kyoto University are given. The principle of this instrument is based on a variable capacitor transducer, and the frequency changes of a crystal oscillator due to the ground strain are multiplied by ten, a hundred or a thousand times. After the comparison with a standard frequency, the differences are recorded on a frequency meter. One millimeter of trace displacement corresponds to a plate movement of about 28 Å of the variable capacitor, and a strain of 2.8×10^{-10} is detectable when the standard length is 10 meters.

This instrument is stable against the humidity, atmospheric pressure and temperature, and good for the observation of earth tides, crustal deformations and seismic strains.

Introduction

An extensometer having the transducer of a variable capacitor type for secular, tidal and seismic strains was devised by H. Benioff[1]. Recently, observations of the earth's strain with extensometers of the same type have been made at Ogdensburg by M. W. Major and others. The sensitivities of their extensometers are near 3.5×10^{-10} per millimeter for the recording of earth tides, and near 2.0×10^{-11} per millimeter for seismic strains at periods nearing 200 seconds[2].

The sensitivities of the extensometers at Dalton and Isabella are both 5.2×10^{-10} for 1 millimeter deflection of the records[3].

The newly devised extensometer described in the present paper is of the variable capacitor type, similar to that of Benioff's. The changes of the capacitance due to the ground strain cause to frequency changes of the crystal oscillator, which are recorded by a frequency meter. First, the construction of this instrument is given and then the observational results from this at the Kamigamo Geodetic Observatory, Kyoto and Osakayama Observatory, Ōtsu are reported.

The Principle of the Instrument

The block diagram of this extensometer is shown in Fig. 1. In general, an extensometer consists of some standard length which extends between two arbitrary points in the earth. One end of the standard is fixed to the earth and the other is free. Variations of the strain of the earth between the ends of the standard produce relative displacement between the free end of the standard and the earth near it, which is detected by a transducer.

As the transducer of this extensometer, two disks are mounted respectively

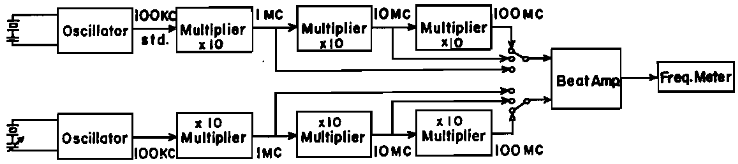

Fig. 1. Block diagram of the extensometer.

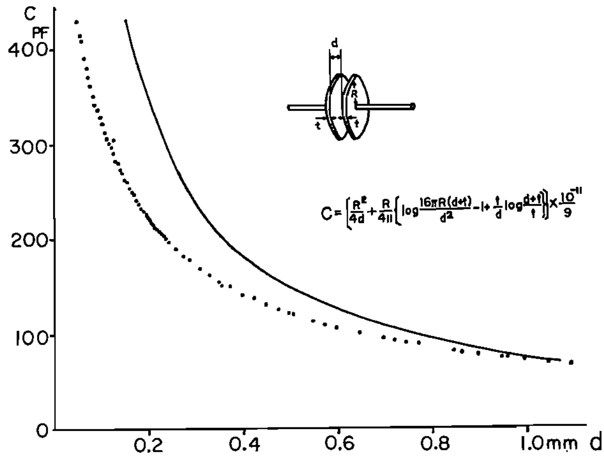

Fig. 2. Change of the capacitance versus the distance between the plates.

on the free end and the block settled on the ground near it, in the way that the both disks form a parallel-plate condenser. This capacitor is connected in series with the crystal of a crystal controlled oscillator. By the variation of the strain of the earth, the distance between the two disks varies to cause the variation of the capacitance of the parallel-plate condenser and then the frequency change of the output of the crystal oscillator. Next, the frequency of the output is multiplied by ten, a hundred or a thousand times and mixed with the output of the other standard crystal oscillator, to make the difference between their frequencies. The mixed beat is recorded on a frequency meter.

Detailed explanations of each part of this instrument are given in the following.

As the length standard, a super-invar rod with a diameter of 1 cm is used. The disks which form the variable capacitor are made of brass, plated with chronium and isolated from the super-invar rod by teflon. The diameters of the disks are about 10 cm and somewhat different from each other to make the variation of the capacitance by transversal displacements as small as possible. For the calibrations of the sensitivities and the adjustments of the instrument, the block, on which the brass disk is mounted, is able to be slid by a micro-screw so as to vary the distance between the two disks. The capacitance of the parallel-plate condenser versus the distance is shown in Fig. 2. The solid circles are the experimental results and the solid line the theoretical curve. It is suspected that the difference between them is mainly due to the deviation of the disks from the parallel state. The parallel-plate condenser of the two disks is inserted in series with the crystal into one arm of the bridge of the oscillator based on the bridge-stabilized circuit developed by L. A. Meacham[4], and the crystal is oscillated in the near vicinity of the series-resonance frequency. The crystal used is of DT cut, its resonant frequency is 100 kc/s and its frequency-temperature coefficient is zero at about 15°C, for the temperature in an adit is about 15°C, in which continuous observations of the earth movements are generally carried out.

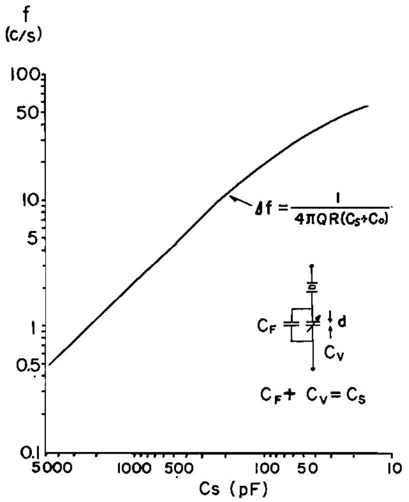

Fig. 3. Frequency change to the capacitance C_S.

One may express the difference Δf between the frequency f' which is generated by a crystal when a capacitance C_s is inserted in series with the crystal and the series-resonance frequency f of it, as

$$\Delta f \equiv f' - f = \frac{1}{4\pi Q R_1 (C_0 + C_s)},$$

where R_1 and C_0 are the equivalent resistance and equivalent parallel capacitance of the crystal, respectively. Substituting the values of 71.5Ω, 27 pF (containing the capacitance of the lead wire) and 47.34×10^4 for R_1, C_0 and Q of the crystal, one can obtain the relation between Δf and C_s, which is shown in Fig. 3. The difference Δf increases as the capacitance C_s decreases, and the oscillation tends to become

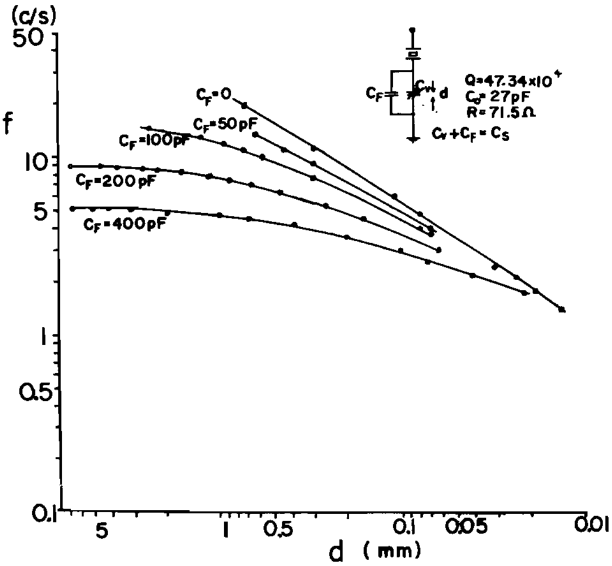

Fig. 4. Frequency changes versus the distance between the plates.

unstable. When an arbitrary fixed capacitance C_F is entered in parallel with the variable capacitance, for the adjustments of the generated frequency and sensitivity of the instrument, the frequency generated by the oscillator varies with C_F and the distance d between the parallel disks as shown in Fig. 4. As is seen in the Figure, by narrowing the distance between the disks so as to increase the capacitance and decreasing the fixed capacitance C_F, the frequency change for unit change of the distance becomes larger and the sensitivity higher.

The output frequency of 100 kc/s$+\Delta f$ modulated thus by the change of the distance between the two disks, is multiplied up to 1, 10 or 100 Mc/s by the frequency multiplier, and mixed with the standard frequency multiplied up to the same order. The frequency difference is recorded by the frequency meter. The minimum scale and frequency range measurable by the frequency meter used at present are 0.02 c/s and from 49 c/s to 51 c/s, respectively. For example, in the case of multiplication up to 100 Mc/s, the frequency change of 0.02 c/s corresponds to 0.00002 c/s at 100 Kc/s and 0.002 micron change of the distance between the disks is detectable, because a frequency change equivalent to 0.1 mm change of the distance is about 1 c/s, according to the results shown in Fig. 4, when the distance d and the fixed capacitance C_F are 0.5 mm and 100 pF, respectively. This means that the magnification of the instrument is about 1250000 since the minimum scale of the recorder is 2.5 mm and that we can detect a strain of 2×10^{-10} by this extensometer when the standard length is 10 m.

However, one must take notice of the stability of the crystal oscillator. Namely, the stability of the oscillator is required to be within 2×10^{-10} in case of multiplication up to 100 Mc/s, because the frequency change of 0.02 c/s corresponds to 0.00002 c/s at 100 Kc/s. It is not necessarily difficult when a crystal of GT or AT cut of high stability is used. The stability of the crystal used at present is within 2×10^{-9} per day and out of the question in case of multiplication up to 10 Mc/s.

Besides, we can raise the sensitivity by narrowing the distance between the disks.

Instrumentation

Fig. 5 is a part of the topographic map of the Kyoto and Shiga Prefectures. The Kamigamo and Osakayama Observatories are located at 35°04′N., 135°46′E. and 34°59′N., 135°51′E, respectively, as indicated by the solid circles in the Figure. The elevation of both Observatories are 190 and 160 m, and the geology near them being the paleozoic system. Their plane figures are shown in Fig. 6. The length of the adit of the Kamigamo Geodetic Observatory is 21.5 m, and the extensometer was settled at about 10 m inward from the entrance. In the inner room, from which the site of the extensometer was partitioned off by a door, four tiltmeters of horizontal pendulum type, a gravimeter of Ichinohe's type[5], a barograph and a thermometer have been operated, together with a bow-string type extensometer with a standard length of 5 m. The extensometer of the variable capacitor type was set up on Dec. 1, 1963 and the observation was carried on until Oct. 13, 1964. The standard

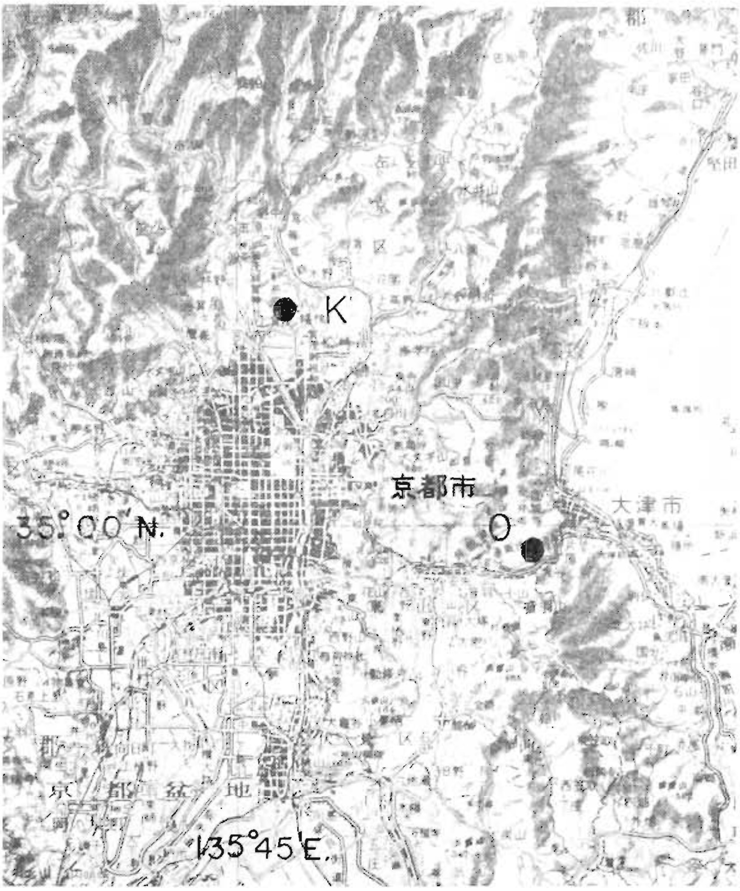

Fig. 5. Topographic map near the observatories.
K : Kamigamo Geodetic Observatory
O : Osakayama Observatory

length and azimuth were 3 m and N 25° E, respectively. Photo. 1 is a view of the extensometer.

After the test observation at Kamigamo, we removed the extensometer to the Osakayama Observatory and have continued the observation from July 6, 1965, with a standard length of 10 m. The Osakayama Observatory consists of two abandoned tunnels of old railways, where observations of the earth's movements and tides have been continued by I. Ozawa, since 1947[6]. The extensometer of the new type is installed at a place 120 m' distance from the entrance on the Ōtsu side in the southern tunnel. The azimuth of the extensometer is S 38°W.

The Observational Results at Kamigamo and Osakayama

It has been ascertained from the observation by the bow-string type extensometer that the changes of the atmospheric pressure and the rainfalls

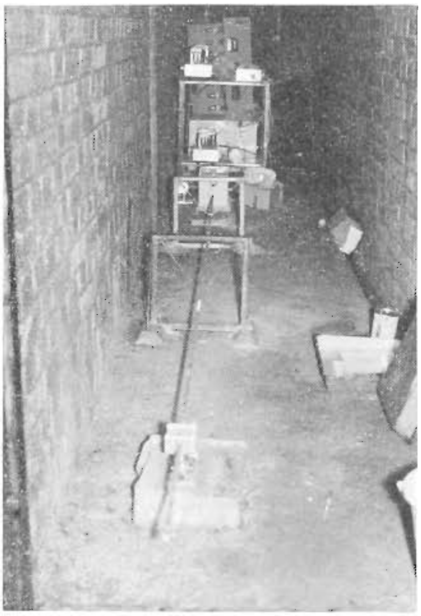

Photo. 1. The extensometer of the variable capacitor type.

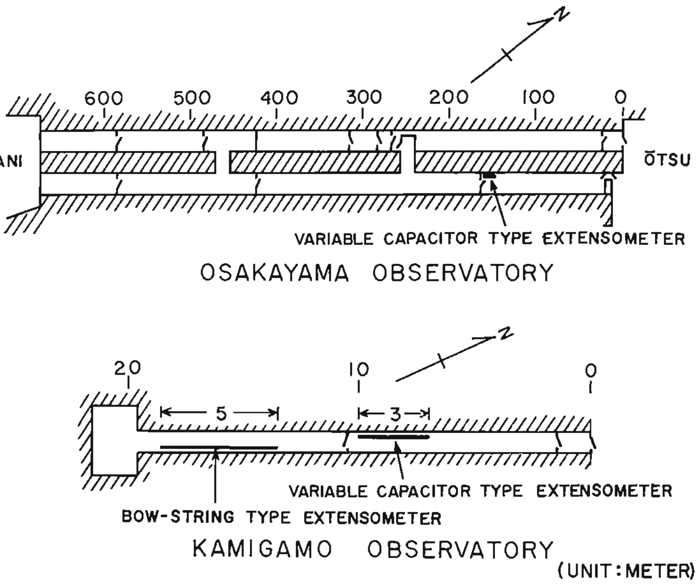

Fig. 6. Plane figures of the observatories and locations of the instruments.

gave rise to the deformations of the ground near the adit of the Kamigamo Geodetic Observatory considerably, because of shallowness of the observation room. Therefore, a fixed capacitance of 600 pF was inserted in parallel with the variable capacitance of the disks in order to reduce the sensitivity,

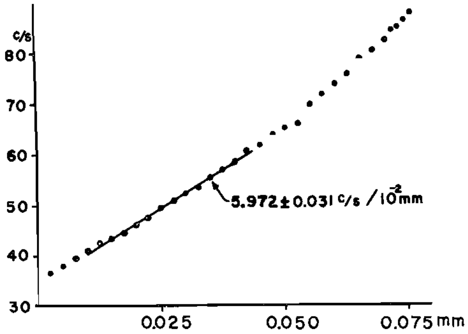

Fig. 7. Frequency change versus the distance between the plates when multiplied up to 10 Mc/s.

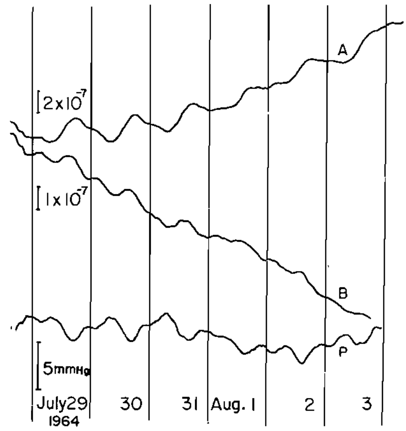

Fig. 8. Comparison among the ground strains observed by the extensometers of the variable capacitor type (A) and of the bow-string type (B), and the atmospheric pressure (P).

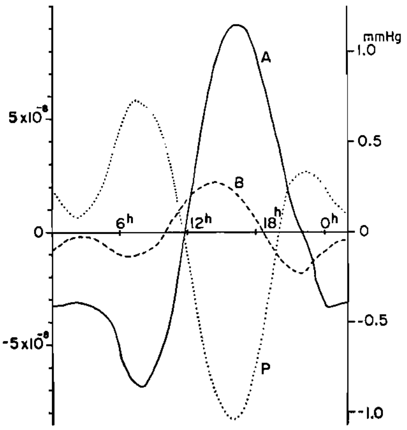

Fig. 9. Mean daily variations of the ground strains observed by the extensometers of the variable capacitor type (A) and of the bow-string type (B) and the atmospheric pressure (P).

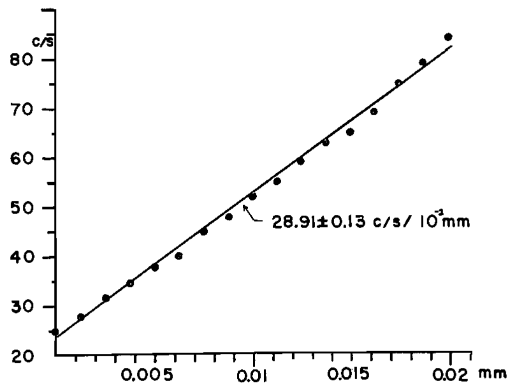

Fig. 10. Frequency change versus the distance between the plates when multiplied up to 10 Mc/s.

and the frequencies were compared by multiplying them up to 10 Mc/s.

The magnification of the extensometer was calibrated by displacing the disk directly with the micro-screw and reading the frequency changes of the output beat. The results are shown in Fig. 7. The gradient of the line in the Figure was determined by the method of least square in the frequency range from 40 c/s to 60 c/s. The value is 5.972 ± 0.031 c/s per 0.01 mm. As the standard length was 3 m, the strain corresponding to the frequency change of the minimum scale of 0.02 c/s on the recorder was 1.11×10^{-8}. Fig. 8 is a comparison among the records of the extensometer of the variable capacitor type and the bow-string type, and the atmospheric pressure. The records of both extensometers show good correlation with the pressure, such as the ground is compressed with the ascention of the pressure. The mean daily variations of the extensomentric records and the atmospheric pressure observed from July 22 to Sept. 7, 1964, are shown in Fig. 9. The pressure change of 1 mmHg generates strains of about 2×10^{-8} and 9×10^{-8} at the deep and shallow part in the adit. It is apparent that the shallower the observation room is, the larger the effect of the pressure on the ground is. The discrepancy, as seen in Fig. 8, between the records observed by the two extensometers may be due to the difference of such local conditions as room temperature, underground water and the effect of rainfalls.

Since the ground-strain noise was too large to carry out the observation under a high sensitivity, we removed the extensometer to the Osakayama Observatory. Photo. 2 is an example of the record at Osakayama. The sensitivity was calibrated by the same procedure. The results are shown in Fig. 10. As the frequency change multiplied up to 10 Mc/s is 28.91 ± 0.13 c/s per 0.01 mm, the deflection of a minimum scale on the recorder corresponds to a strain of 6.92×10^{-10}. In this case, the magnification is about 360000, since the minimum scale is 2.5 mm.

In Photo. 2, a sudden change of the strain of about 3×10^{-9} is seen from $08^h 30^m$ to 09^h20^m. on Aug. 29, 1965. This may be a similar deformation of the ground reported by I. Ozawa[7].

The amplitude of M_2-constituent obtained from Dec. 1 to Dec. 30, 1965, by the harmonic analysis is 7.3×10^{-9}, which is larger than the value determined by I. Ozawa[8].

Regular changes of the strain of the period of 2 or 3 minutes are seen in Photo. 2, the amplitudes of which amount at 10^{-9} when they are large. They are not the phenomena from the instrumental source but the real ground deformations. The origin remains unexplained at present.

Photo. 3 is the record of the earthquake of Nov. 13, 1965. This extensometer is usable for observations of seismic strains by increasing the recorder-speed. The jagged changes of the strain seen in the Photograph are caused by the pumping of the underground water at about 200 m' distance from the Observatory[9].

When the pen of the recorder reaches either end, the pen is returned automatically to the middle of the paper by a compensative micro-condenser in order to prevent the scale-out. Otherwise, it is difficult to carry out the continuous observation under such a high sensitivity. The gap of the record in Photo. 3 is one of the reset.

To examine the stability of this extensometer, we carried out a test observation at Osakayama, on which the standard length was reduced to about 50 cm. In this case, the magnification of this instrument remained unchanged and the sensitivity decreased. Namely, the standard length was shortened by one-twenty and the sensitivity came to 1.4×10^{-8}. The record from this test was almost straight. This means that there is little drift due to the transducer and circuit, and the extensometer is stable against disturbances such as the humidity, atmospheric pressure and so on, except effects on the rod of the standard length.

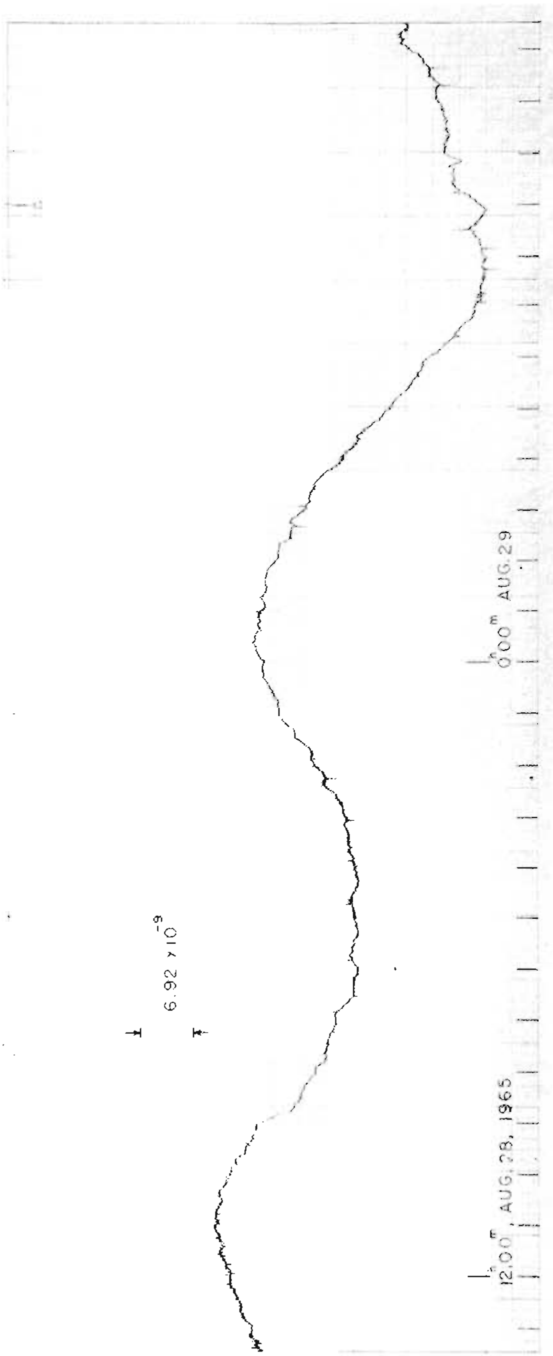

Photo. 2. An example of the record at Osakayama.

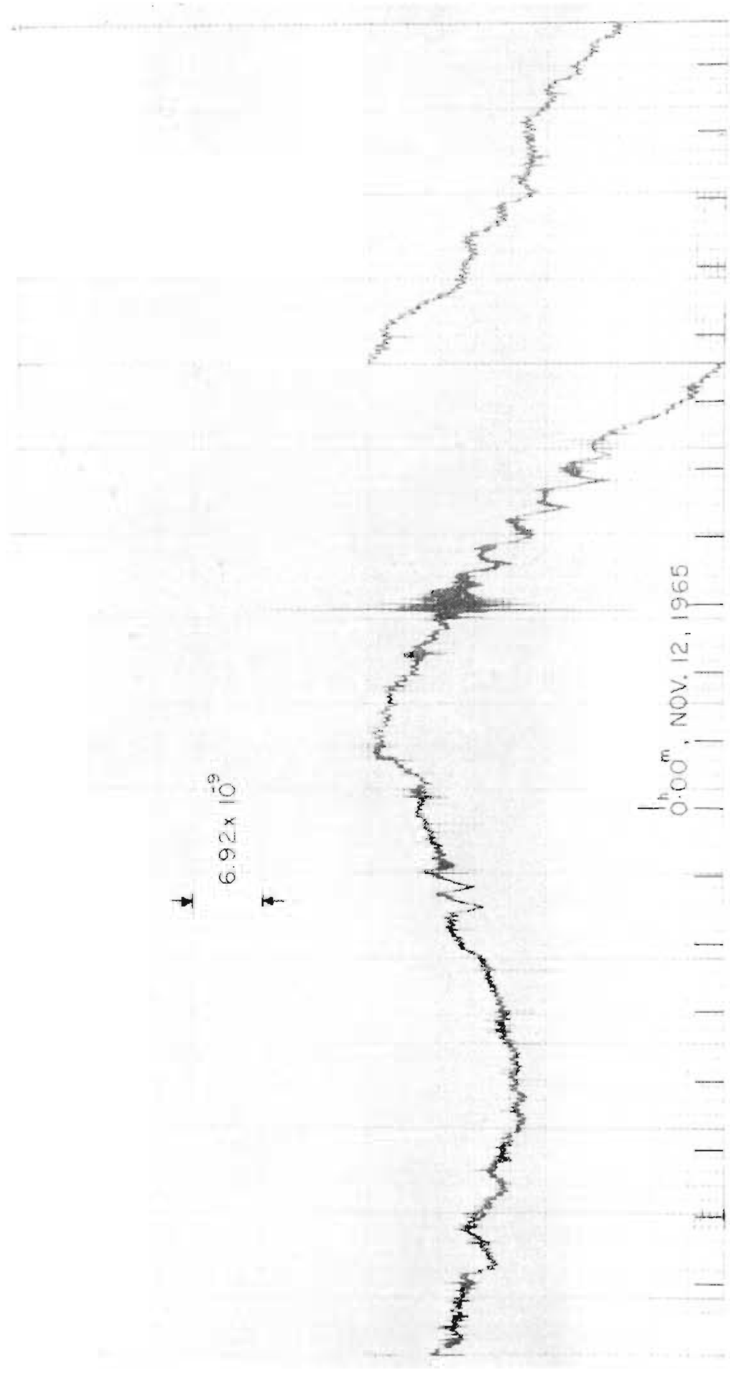

Photo. 3. Strain record of the earthquake of Nov. 13, 1965.

In conclusion, this extensometer is good for observations of earth tides, crustal deformation and seismic strains.

Acknowledgement

I am sincerely thankful to the late Prof. Eiichi Nishimura for his kind guidance and Dr. Yutaka Hiruta of the Radio Research Laboratories for his lead in planning and assembling the instrument. I am grateful to Prof. Izuo Ozawa, Prof. Michio Takada and Mr. Yutaka Tanaka for much useful advice. My thanks go also to Messrs. Masaaki Kato and Masaru Yamada for their kind help for the installation of the equipment and the observation.

References

1) Benioff, H. : A Linear Strain Seismograph, Bulletin of the Seismological Society of America, Vol. 25, 1935, 283–309.
2) Major, M. W. et al. : On Elastic Strain of the Earth in the Period Range 5 Seconds to 100 Hours, Bulletin of the Seismological Society of America, Vol. 54, 1964, 295–346.
3) Benioff, H. : Fused-Quartz Extensometer for Secular, Tidal, and Seismic Strains, Bulletin of the Geological Society of America, Vol. 70, 1959, 1019–1032.
4) Meacham, L. A. : The Bridge-Stabilized Oscillator, Proceedings of the Institute of Radio Engineerings, Vol. 26, No. 10, 1938, 1278–1294.
5) Ichinohe, T. : Study on Change of Gravity with Time, Part 1, Memoirs of the College of Science, University of Kyoto, Series A, Vol. 27, No. 3, 1955, 289–316.
6) For example
Ozawa, I. : On the Observations of the Earth Tide by Means of Extensometers in Horizontal Components, Bulletin of the Disaster Prevention Research Institute, Kyoto University, No. 46, 1961.
7) Ozawa, I. : On the Extensometer of Which Magnifier is a Zöllner Suspention Type Tiltmeter, and the Observations of the Earth-Strains by Means of the Instruments, Journal of the Geodetic Society of Japan, Vol. 6, No. 1, 1960, 1–5.
8) Ozawa, I, : On Observations of the Ter-Diurnal Component of the Earth's Tidal Strain, Special Contributions, Geophysical Institute, Kyoto University, No. 4, 1964, 1–8.
9) Ozawa, I. : Read at annual meeting of the geodetic Society of Japan, 1964.