On the Extensometer of a Variable Capacitor Type

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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 $2.8 \times 10^{-10}$ 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. 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 $3.5 \times 10^{-10}$ per millimeter for the recording of earth tides, and near $2.0 \times 10^{-11}$ per millimeter for seismic strains at periods nearing 200 seconds.

The sensitivities of the extensometers at Dalton and Isabella are both $5.2 \times 10^{-10}$ for 1 millimeter deflection of the records.

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, Otsu 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
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\(^0\), 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.

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

$$\Delta f = f' - f = \frac{1}{4\pi QR_1(C_0 + C_i)},$$

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 $47.34 \times 10^4$ for $R_1$, $C_0$ and $Q$ of the crystal, one can obtain the relation between $\Delta f$ and $C_i$, which is shown in Fig. 3. The difference $\Delta f$ increases as the capacitance $C_i$ decreases, and the oscillation tends to become

\[\text{Fig. 3. Frequency change to the capacitance $C_i$.}\]

\[\text{Fig. 4. Frequency changes versus the distance between the plates.}\]
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 $100\,\text{kc/s} + \Delta f$ 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 $2 \times 10^{-10}$ 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 $2 \times 10^{-9}$ 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 $2 \times 10^{-9}$ 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, 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
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 19476). 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
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,
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 $5.972 \pm 0.031$ 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 $1.11 \times 10^{-8}$. 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 ascension of the pressure. The mean daily
variations of the extensomeric records and the atmospheric pressure ob-
served from July 22 to Sept. 7, 1964, are shown in Fig. 9. The pressure
change of 1 mmHg generates strains of about $2 \times 10^{-8}$ and $9 \times 10^{-8}$ at the deep
and shallow part in the adit. It is apparent that the shallower the observa-
tion 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 ex-
tensometers 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 $28.91 \pm 0.13$ c/s
per 0.01 mm, the deflection of a minimum scale on the recorder corresponds
to a strain of $6.92 \times 10^{-10}$. 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 $3 \times 10^{-9}$ is seen from 08h
30m to 09h20m. 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 $7.3 \times 10^{-8}$, which is larger than the value determined by I.
Ozawa.\(^7\)

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 Ob-
servatory.\(^7\)

When the pen of the recorder reaches either end, the pen is returned auto-
matically 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 observa-
tion 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 $1.4 \times 10^{-8}$. 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.
In conclusion, this extensometer is good for observations of earth tides, crustal deformation and seismic strains.

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References

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