BULLETIN OF THE EARTHQUAKE
RESEARCH INSTITUTE
Vol. 46 (1968), pp. 957-964

47. *Electrical Conductivity of Strained Rocks. The Fourth Paper. Improvement of the Resistivity Variometer.*

By Yoshio YAMAZAKI,

Earthquake Research Institute.

(Read Dec. 26, 1967 and May 28, 1968.—Received May 30, 1968.)

Summary

The resistivity variometer has been improved by making use of graphite electrodes and an automated balancing technique. It turns out that a resistivity change of the order of 10^{-4} in its rate can easily be recorded by an observation at Aburatsubo where resistivity change caused by tidal loading is fairly great. It is concluded that an observation with a sensitivity much higher than the present one could be performed at a place where noises are small.

1. Introduction

Much effort has been made in improving the resistivity variometer[1], which had already been described by the writer[1], because the variometer was not entirely free from drift and suffered from noises of unknown origin. The main points of the improvement so far made will be reported in the following.

2. Points improved

2-1. *Electrode*

Copper electrodes plated with silver were used during the earlier period of observation. It turns out, however, that the electrodes, by which electric currents are driven into the ground, tended to be covered with whitish film after some time accompanied by increasing noises. Even a thinning of the electrodes was observed. Similar phenomenon was also experienced for an electrode made of lead.

It is beyond the scope of the present study to look into such an electro-chemical phenomenon, so that trial-and-error search was made

1) Y. YAMAZAKI, *Bull Earthq. Res. Inst.*, **45** (1967), 849-860.

for an inactive material eventually arriving at a sufficiently stable electrode made of graphite. In actual observation, graphite electrodes 2 cm in diameter are being used.

2-2. *Input transformer and phase detection*

Unlike the measuring circuit of the resistivity variometer as reported in the third paper[1], the circuit is formed in such a way that the small voltage, i.e. the deviation from an equilibrium, is led to a 67 c/s filter through a coupling transformer. It becomes therefore possible to earth each chassis of the system.

The signal voltage was rectified after being amplified in the earlier model. It was required, therefore, to operate the system at a state slightly deviating from the exactly balanced point, otherwise no distinction was made between increase and decrease in the resistivity. That such a method of observation leads to considerable instability and low sensitivity has been found soon after the first experiment in the field.

In the autumn of 1967, a new model of the variometer, which works on the principle of phase detection, was constructed. Fig. 1 shows the block-diagram of the model. As can be seen in the circuit, the 67 c/s voltage taken from the oscillator is used as the reference voltage. In

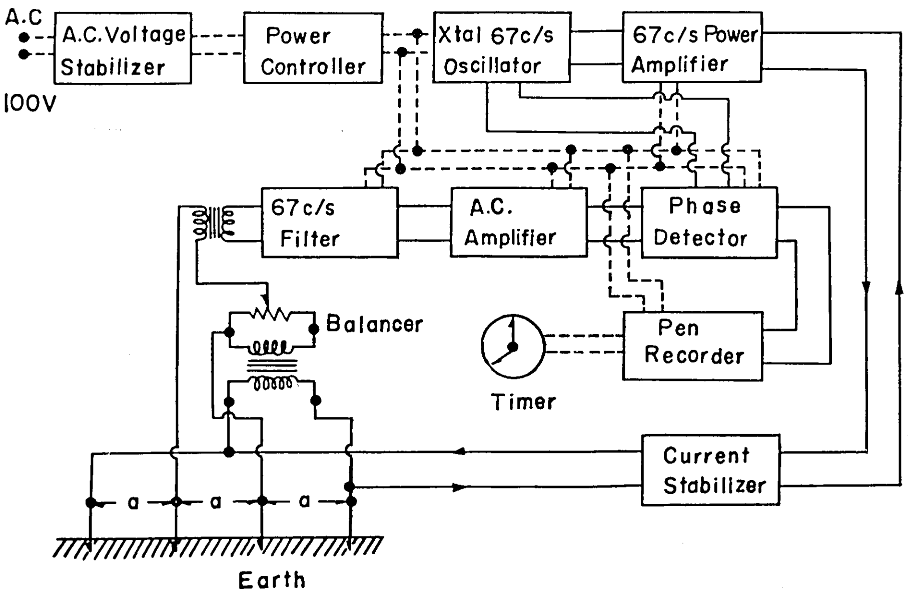

Fig. 1. Block-diagram of a resistivity variometer based on phase detection.

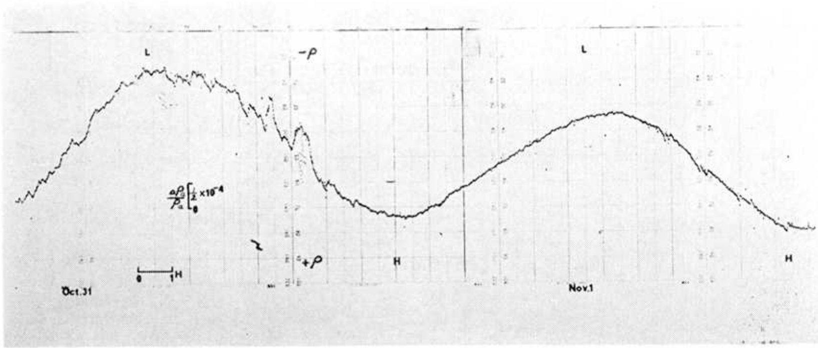

Fig. 2. Resistivity changes as recorded by the phase-detection variometer at Aburatsubo on Oct. 31 and Nov. 1, 1967.

Fig. 2 is shown a record of resistivity change as observed at Aburatsubo. The observation site is the same as that reported in the third paper. It may be said that changes in the resistivity in association with the tidal loading at Aburatsubo can be recorded very accurately by the improved variometer.

2-3. *Automatic control of the balance*

It has been noticed that the variometer as mentioned in the last section sometimes experiences a drift of unidentified origin although it seems likely that seasonal changes, changes accompanied by remarkable rain-falls and the like have something to do with the drift. After a conspicuous drift, the condition for balance does not hold any more. In that case, the output voltage from the balancing circuit is not proportional to the change in the resistivity.

It is therefore required for an accurate observation with a constant sensitivity to keep the balanced state all the time. This can be made by adjusting the variable resistance of the balancing circuit in such a way that the output voltage is always zero. This is readily accomplished by making use of the automatic control technique with a servo-motor.

Fig. 3 shows the block-diagram of the automated resistivity variometer, its working principle being much the same as the previous apparatus based on phase detection. A small output voltage from the balancer is amplified and applied to one of the windings of the servo-motor. A 67 c/s reference voltage of about 100 volt is also applied to another winding of the motor. A helical variable resistance of 100 Ω for 10 turns is coupled with the rotating shaft of the motor through a gear-work. As the motor rotates in such a way that the output voltage from the balancer becomes zero, the balanced state is always kept by the servo-mechanism.

The rotation of the motor can be recorded by either method. For convenience's sake, the rotation is converted, through another gear-work, to that of a variable resistance from which a voltage proportional to

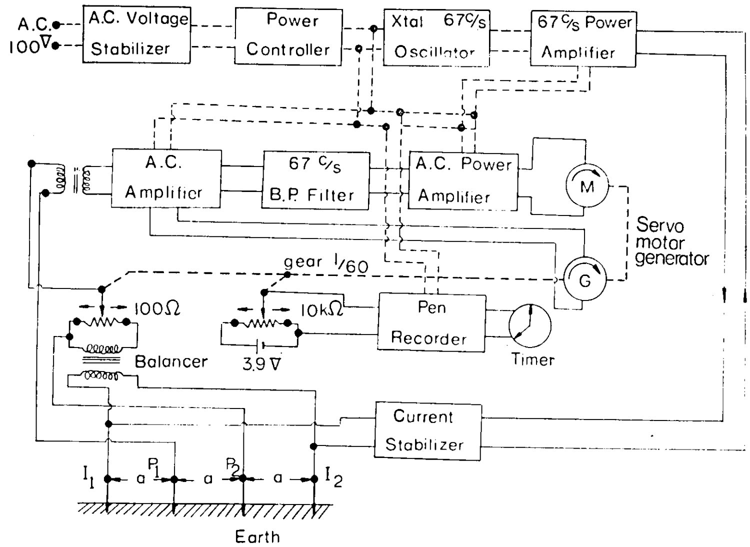

Fig. 3. Block-diagram of the automated resistivity variometer.

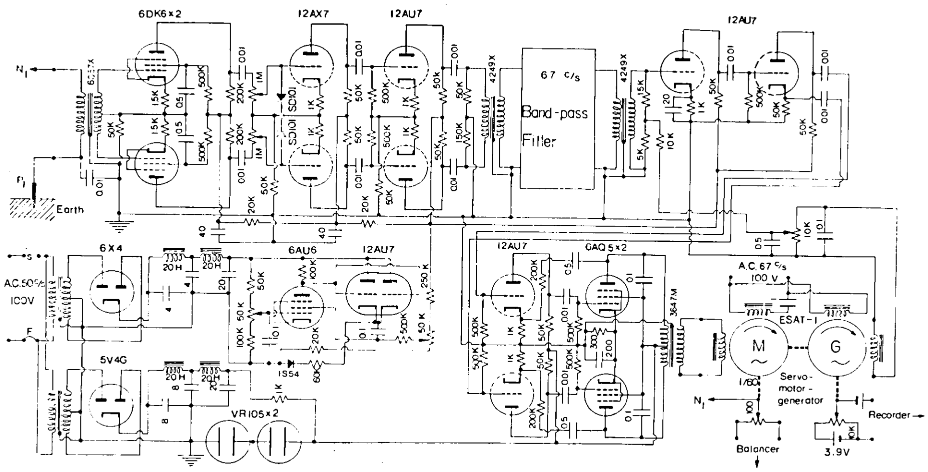

Fig. 4. Electric circuits for the amplifier, power supply and so on of the automated resistivity variometer.

the rotation angle can be supplied potentiometrically to a multi-channel pen-writing recorder. In actual observation, two variable resistances are used in order to provide high- and low-resistivity recordings.

The circuits for the amplifiers, power supply and the like are illustrated in Fig. 4. The gain of the amplifier is so high that the motor performs a sort of hunting. In order to suppress the hunting, the output voltage, which is proportional to the rotation speed, from a tacho-generator, which shares the same rotation axis with the servo-motor, is fed back to the amplifier. In such a way, we can eliminate rapid changes without affecting slow changes.

3. Field test of the automated resistivity variometer

The automated resistivity variometer has been at work at Aburatsubo since May, 1968. The observation site is exactly the same as that reported in the third paper[1]. The No. 3 arrangement of electrodes (N 81°W) as indicated in Table 1 of the third paper is adopted.

In Fig. 5 are shown the high- and low-sensitivity records of resistivity change on May 16 and 17, 1968. Changes in the resistivity associated with tidal loading can be clearly seen. A strong earthquake of M = 7.8 took place off the southern coast of Hokkaido Island at 9 h 49 m. A gradual change lasting a few minutes is observed on the record. An anomalous change also seems to have started about two hours earlier. Nothing is known about the cause of these changes at the present stage of investigation. A conspicuous after-shock of M = 7.5 took place at 19 h 39 m on the same day whence a small-scale change is seen on the

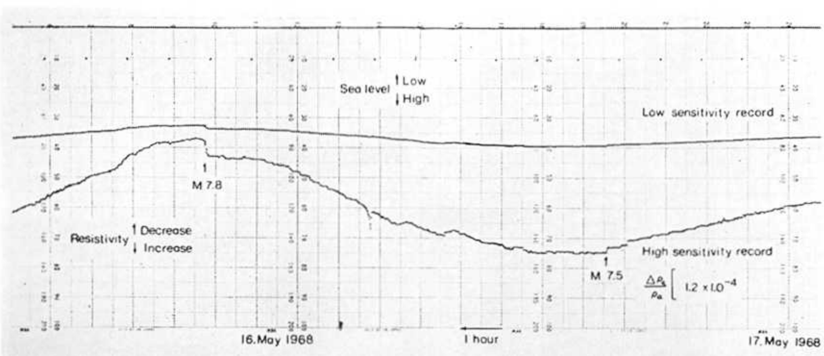

Fig. 5. Resistivity changes as recorded by the automated resistivity variometer at Aburatsubo on May 16 and 17, 1968. Times of earthquake occurrence are shown with arrows.

record, too. Zig-zag traces of very small amplitude superposing on the gradual change seem likely to be caused by the seiche in Aburatsubo Bay judging from the period.

The double amplitude of the rate of resistivity change $\Delta\rho/\rho$ as shown in Fig. 5 amounts to some 5×10^{-4}, while it is known that the change in linear strain $\Delta L/L$ in the respective direction amounts to only 10^{-6} or a little smaller. The $\frac{\Delta\rho}{\rho}\Big/\frac{\Delta L}{L}$ value therefore amounts to the order of 10^3 as has frequently been pointed out.

4. Concluding remarks

Many improvements are made for the proto-type of the resistivity variometer. The final model based on a servo-mechanism seems to be satisfactory for recording changes in the resistivity accompanied by tidal loading at Aburatsubo. As the present observation site is fairly noisy because of seiches and high waves on windy days, stray electric currents from railways and so on, it would not be practicable to make the sensitivity higher. But it is readily possible to perform an observation of higher sensitivity by a factor $10\sim10^2$ provided the naturally occurring noises are small enough. It is therefore intended to make observation with the present variometer at a place where the effect of tidal loading is not as large as that of the present observation.

In conclusion the writer wishes to express his sincere thanks to Professor T. Rikitake under whose supervision the present work has been conducted. Part of the expense for the present work has been defrayed from a fund given to Professor T. Rikitake from the Ministry of Education.

Appendix. Long-term change in the resistivity at Aburatsubo

The resistivity variometer operated at Aburatsubo has been suffering from drifts of unidentified origin. For the purpose of examining whether the drift is caused by instrumental instability or not, the resistivity values as measured from time to time are plotted as can be seen in Fig. 6.

The resistivity ranges from 2.18 to 2.38 kΩ-cm, so that it turns out that the resistivity fluctuates whithin a range of 10 per cent. Since the full range of the record of resistivity change is only 10^{-4}, it is quite natural that the record sometimes drifts away from the recording paper.

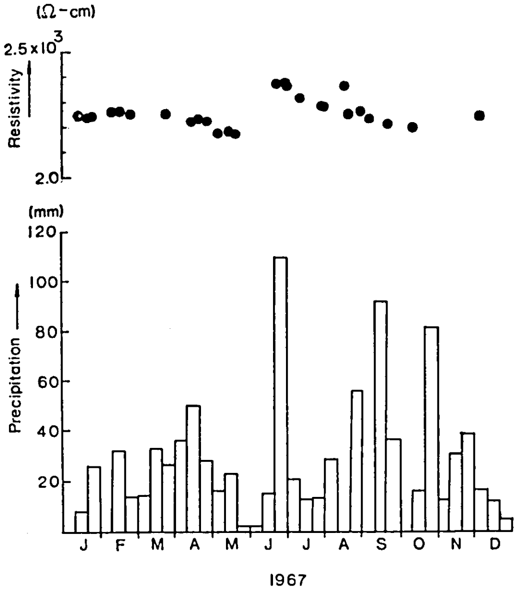

Fig. 6. Long-term changes in the resistivity at Aburatsubo. Ten-day sums of precipitations are also illustrated.

The writer did not expect such a large resistivity change of long-range in the beginning of the present observation because the electrodes are set in a cave sheltered from rain-falls. In Fig. 6 are also shown the precipitations at Aburatsubo as calculated for every one-third of a month. Although no clear relation between the resistivity value and the rain-fall can be seen in the figure, the high resistivity for the 1967 summer might be a result of the preceding dry period. As the resistivity values seem to be influenced by rain-fall to some extent, it would be important for future observations aiming at detecting a premonitory effect of earthquake occurrence to install the variometer at a place where no marked influence of rain-fall is observed.

As has been reported in the third paper[1)], changes in the height of sea-level affect the resistivity value, too. But it is estimated that a change in the height of sea level of 1 m is required for a 10 per cent change in the resistivity. It is hence implausible to attribute the resistivity change observed to fluctuations of the sea-level.

47. 岩石変形と電気伝導度変化（第四報）比抵抗変化計の改良

地震研究所　山　崎　良　雄

比抵抗変化計の増幅および記録部を地震研究所油壺地殻変動観測所内に設置し，観測坑に検出用電極4本を 1.6 m の間隔で N 81° W の方向に埋め，1967年1月から大地比抵抗の連続観測をおこなつている．

観測の初期には交流電流にも拘わらず銀塗布銅電極は電触作用を次第に受けて電極表面の地表面に接する部分が損傷した．このため電極と大地間の接触が劣化して，電流の通電と記録の安定に支障を与えた，対策として地電流常時観測用の鉛管，素焼陶器入硫酸銅寒天電極，周囲に木炭を埋設した銅電極などについて実験の結果，いずれも不適当であり graphite 棒のみが長期間観測に極めて優秀な特性を保持することがあきらかになつた．

増幅および記録部は 67 c/s メカニカルフィルターを結合した単一周波交流増幅および連続記録方式から，入力の極性選別に有利な位相検波方式および打点式多成分記録器に途中で交換した．これにより短周期不明確信号を除去して SN 比が増大し極めて鮮明な記録になつた．しかし比較的に大きく変化する比抵抗絶対値の経年変化にはこの方式では零点が追従不可能なので，さらに自動平衡記録方式に変更した．

自動平衡記録方式はサーボ機構を比抵抗変化計の平衡器に取付け，大地比抵抗の微少変化に応じて発生する電圧電極間の数 μV の電圧を増幅して二相交流平衡電動機の回転にかえる．ギアを通して電動機の回転は平衡器のスライド抵抗位置を調整し，67 c/s 帯域増幅器の入力電圧を常時零にすると同時に，この回転量を直流電圧変化に変換して比抵抗変化量を間接的指示法によつて表現する方式とした．これによつて大地比抵抗の自動観測精度は著しく向上することが出来た．