30. *A New-Designed Prospecting Apparatus.*

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(Read June 16, 1953.—Received Oct. 31, 1953.)

1. Introduction.

It is well known that, as a prospecting method for determining the construction of the earth's layers, there is a device which makes use of artificial seismic waves. In this method, the waves are of course generated by a shock applied to the earth's surface by dropping a suitable weight or by exploding a effective dynamite. In measuring the travel times of the waves in the earth, generally at least two seismometers of moving coil type are used for detecting weak seismic waves, which are usually set at two different localities, i.e. A and B on the ground respectively, the locality A being near the shock origin. The output voltages of the transducers of these two seismometers induced by the travelling seismic waves are amplified and then recorded on an oscillograph paper by using an electro-magnetic oscillograph. The travel time of the shock between the two localities A and B is obtained by measuring the distance between the two thresholds of initial motions of the respective wave-phases taken on the paper. Varying the distance between the two localities A and B on the ground by moving the locality B, we obtain the travel time of the shock for respective varied distances, and hence we are able to obtain the "time-distance curve" which is necessary in determining the properties of the stratified layers of the earth. Fig. 1 shows schematically the paths of propagated waves which are excited by a shock. In Fig. 1, if the transducer B is set near the transducer A which is set near the position of the shock origin, the wave propagated directly through the surface of the earth arrives first at the seismometer B. But, if the distance between the two localities of seismometers becomes rather long,

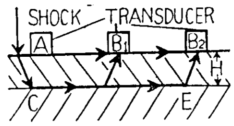

Fig. 1.

the wave which propagates through the second layer arrives at the locality B faster than the direct one, because the velocity in the second layer becomes larger than that in the first, or in other words, the wave propagated through the path $ACEB_2$ becomes faster than that propagated through the path AB_2. Now, the surface of the earth consists generally of a number of layers in which the seismic waves have different velocities respectively, and therefore we can see, on the "time-distance curve", many lines with different tangents in accordance with the layers under the ground. Assuming the boundaries of the stratified layers to be parallel to the surface of the earth, we are able to obtain the depth of the first layer H with the aid of the "time-distance curve", which is determined by the following formula:

$$H=\frac{Z}{2}\sqrt{\frac{v_2+v_1}{v_2-v_1}}\ ,$$

in which Z shows the horizontal distance between the origin and the point which corresponds to the first intersection point of the "time-distance curve", and both v_1, v_2 are velocities corresponding to the first and the second layers respectively, they being directly read off from the tangents of the "time-distance curve".

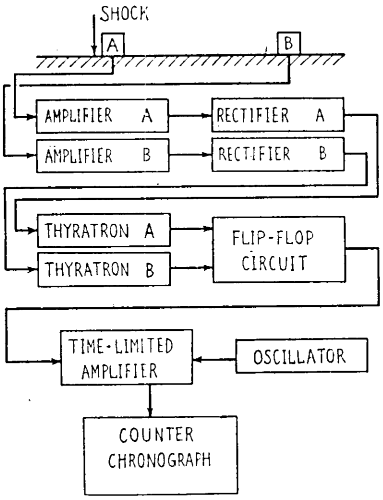

Fig. 2. Block Diagram of the Apparatus.

Now, in the usual method, to obtain the "time-distance curve", we must measure the time interval between the two initial motions recorded on the oscillograph paper, as already explained. In the present prospecting apparatus, however, the procedures of measuring the time interval on the oscillograph paper and using an electro-magnetic oscillograph, are dispensed with and the measuring procedure of the time interval is done automatically by electronic circuits. The principles of the present new-designed apparatus will be explained by both diagramatic and schematic methods as follows. In the block diagram Fig. 2, the output voltages gained from two transducers A and B are fed to the amplifiers A and B respectively. The output of the amplifiers is rectified in the next circuit. The respective output voltages gained from the rectifying circuits appear always in the positive no matter whether the sign of the input voltage given to the rectifying circuit becomes positive or negative, owing to the mechanism of the circuit. The respective output voltages are fed to the following thyratron grids respectively. When the shock waves arrive at the seismometer, the thyratron ignites instantaneously, and then the differentiated pulse appears at the output of it. Next, the two pulses produced at *A* and *B* thyratron outputs are fed successively to the grids of flip-flop circuit. Then the variation of the plate voltages at the flip-flop circuit becomes rectangular as shown in Fig. 3. On the other hand, a local oscillator of 8000 c/s is involved in this instrument and the output voltages of this oscillator are amplified by an amplifier which is controlled by the plate voltage of the above-mentioned flip-flop circuit and is capable of amplifying the 8000 c/s waves during only the time interval in which voltage of rectangular form as shown Fig. 3 is excited. In short, the 8000 c/s waves are amplified during the time interval between the two thresholds of output voltages gained from the two seismometers *A* and *B*. Hence, these waves excited only for finite time interval are fed to the counter chronograph which is constructed to indicate the number of the fed pulse by the neon lamp ignition device. From the above explanation, we can see that when we use the present electronic instrument, we are able to read quickly and easily in direct manner the time interval which is necessary to obtain the "time-distance curve".

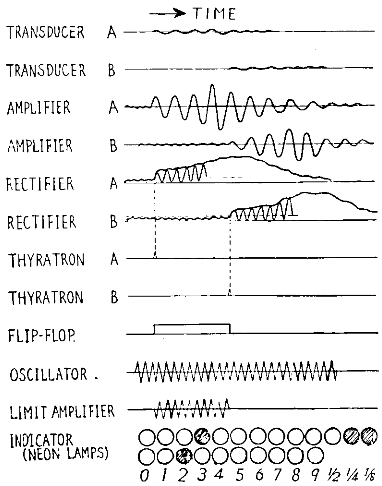

Fig. 3. Schematic Show of the Principle of the Apparatus.

2. Apparatus I. Transducer.

As in the usual seismic prospecting apparatus, the seismometer used for the present apparatus is also composed of an electromagnetic transducer of the moving coil type. The sensitivity of it, however, becomes pretty higher than that of the transducers of the same type used heretofore, because for its mechanical construction we adopt a new design wherein the motion of its moving coil is magnified with

Eden's twin strips[1], one end of which is connected to the moving pendulum weight of the seismometer. Figs. 4a, 4b and 5 show the diagram and the photograph of the seismometer for the present study. The present seismometer consists mainly of the following seven parts: (1) the outer case *A*, (2) the pendulum weight *B*, (3) supporting spring plates C of the weight, (4) a moving coil *E*, (5) supporting lever *F* of the moving coil, (6) the Eden twin strips *D*, and (7) the clamps *G* of

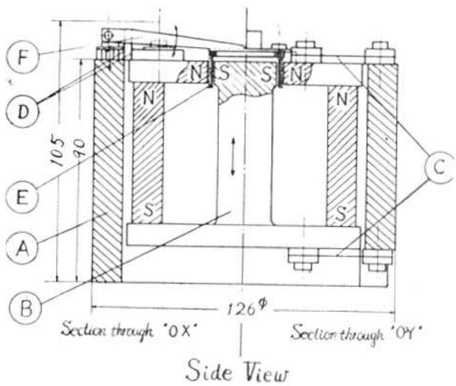

Fig. 4a. Seismometer with Eden's Twin Strips.

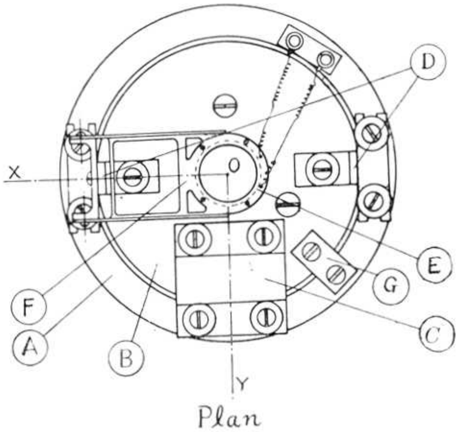

Fig. 4b. Seismometer with Eden's Twin Strips.

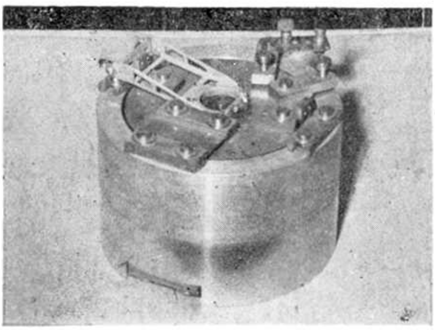

Fig. 5. Seismometer with Eden's Twin Strips.

the weight. The case *A* is made of an Aluminium cylinder of which the inner and outer diameters are 150 mm and 190 mm respectively and the height 150 mm. The pendulum weight *B* of 3 Kg is fixed to and

1) Eden's twin strips is generally used for statical magnifying device as for precise comparator. Both the statical and dynamical properties have been theoretically and experimentally studied by us in a minute manner, and be fully reported in the next occasion.

supported by the ends of the two parallel spring plates C of phosphorous bronze at its top and bottom surfaces respectively and the other ends of these spring plates C are fixed to the case A. Therefore, through the total restitutive forces of the two spring plates, the weight B can only do vertical motions in its small vibration amplitudes. The weight B is composed of two parts: (1) MK permanent magnet of hollow cylinder and (2) mild steel block which is so shaped that the annular gap is prepared for the motion of the moving coil E which moves up and down through the gap where the magnetic flux is concentrated. The coil E is attached to one end of the lever F, the other end of which is fixed to the point of Eden's twin strips D as shown Figs. 4 and 5. The end of one of Eden's twin strips is fixed to the pendulum weight B, and the end of the other strip to the top surface of the case A. The longitudinal axis of Eden's twin strips becomes of course parallel to the vertical axis of the pendulum weight of cylinder. We are able, therefore, to understand, concerning the motion of the moving coil E connected to the weight B with Eden's twin strips, that if the pendulum moves upwards or downwards a little, the movement of the coil becomes also upwards or downwards respectively. But, as a matter of fact, in spite of the infinitesimal movement of the pendulum weight, the coil's movement becomes factually large, because it comes to be magnified greatly by means of both the magnification mechanisms of Eden's twin strips and also the lever system F. Hence, the moving coil with those magnification mechanisms can move through the gap of concentrated magnetic flux with fast speed which becomes larger than that of the pendulum weight. It is characteristic of the present transducer that the sensitivity becomes larger than that of the ordinary transducers of moving coil type. The moving coil is made of 7000 turns of No. 48 enamel covered copper wire and has an electric resistance of 2000 ohms, its mass being 16 grams weight. When the shock waves arrive at the seismometer, it begins to vibrate and the output voltage induced in the transducer becomes of course proportional to the relative velocity between the coil E and the pendulum weight B.

Considering the mass of the coil, we can easily derive, from the fundamental equation of vibration, the relation between dynamical magnification V and geometrical magnification V_G of the seismometer as follows:

$$V = V_G/(1+V_G^2/\mu),$$

where $\mu = M/m$, and M and m are the masses of the pendulum and the coil respectively. From the expression of V, we can obtain Fig. 6

which shows the characteristics of the seismometer. From Fig. 6, we can see that there is a maximum value of V and this value becomes large when the value μ becomes large. It is actually difficult, from

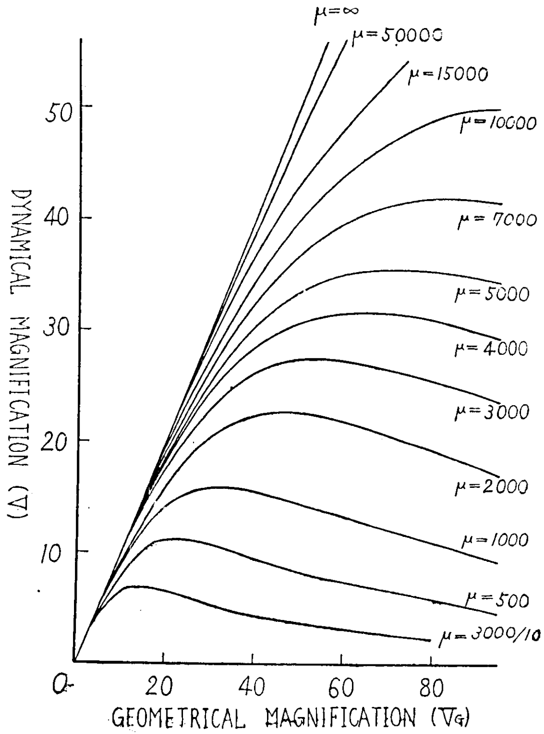

Fig. 6. Characteristic Curve of Seismometer.

the technical point of view, to make the value μ large, and in the present case μ becomes as follows:

$$\mu=(3\,\text{kg})/(16\,\text{gr})=(3000)/(16).$$

Therefore the maximum point of V for the present seismometer has the value $V=6.7$ when $V_G=13.6$.

The natural frequency of the present seismometer becomes about 20 c/s and the sensitivity of it becomes 5 Volt/cm/sec which is almost ten times as large as the ordinary one.

Generally, we know that there are two kinds of magnetic type transducer: (1) the reluctance type and (2) the moving-coil type. From the viewpoint of our request, the moving-coil type is more convenient than the reluctance type, because the reluctance type cannot easily obtain suitable damping of the seismometer in spite of its high gains. The damping h of the present seismometer is expressed by the following formula which is also derived from the basic consideration of both the electro-magnetic transducer and the equation of vibration:

$$h=\varepsilon/n=R/(2nM)\cdot V_G^2/(1+V_G^2/\mu),$$

in which R becomes a constant concerning the electro-magnetic effects and the construction of both the coil and the lever and also h, n and ε are indicated in the following equation which is reduced from equations concerning electro-magnetic transducer:

$$d^2x/dt^2+2\varepsilon dx/dt+n^2x=f,$$

where n is free angular frequency and ε damping coefficient. Here, we can see that the damping becomes proportional to V_G^2 in the range of small value of V_G. In our case, the existence of damping is rather convenient for preventing the noise effect of the ground.

3. Apparatus II. Gate Circuit.

The gate circuit operates between two successive pulses and is composed of the following six parts: (1) two amplifiers, (2) two rectifiers,

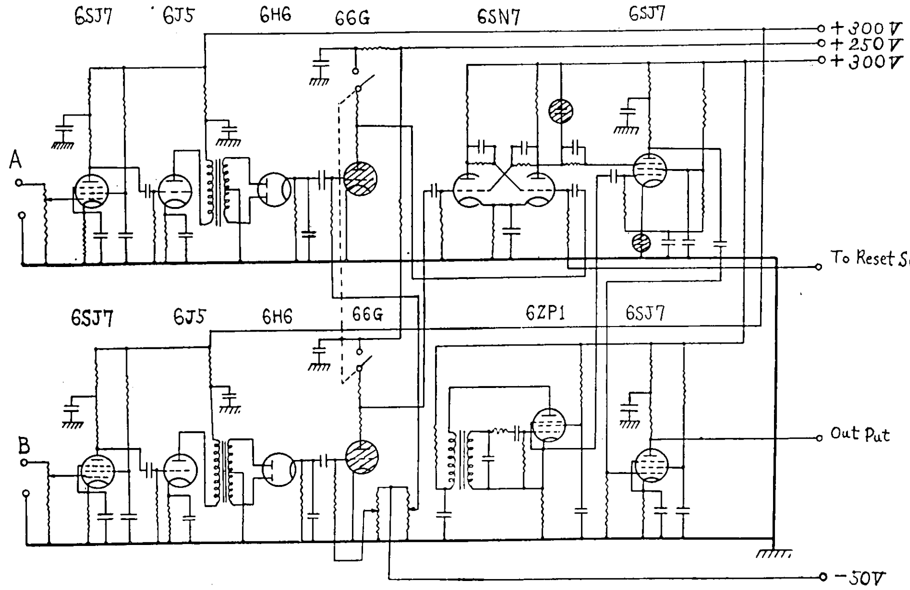

Fig. 7. Gate Circuit.

(3) two thyratron circuits, (4) a flip-flop circuit, (5) a local oscillator and (6) a time-limited amplifier. Fig. 7 is the diagram of this circuit, and its apparatus is shown in Figs. 8a and 8b.

The two amplifiers consist of the two bulbs 6SJ7 and 6J5 respectively, and they amplify the respective voltages gained from the two seismometers. The gains of these amplifiers are regulated by the variable resistances at the inputs and the maximum gains becomes about 50 db. Of course, these two amplifiers are specially designed to obtain their respective voltage supply independently for the purpose of avoiding any coupled relation which shall be excited between these two amplifiers.

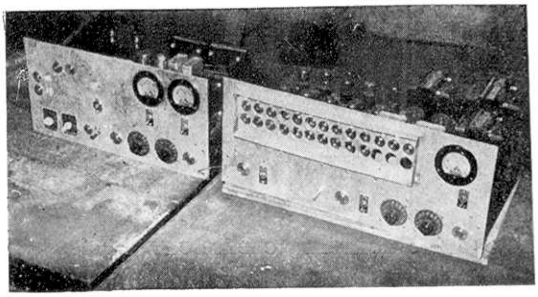

Fig. 8a. Left: Gate Circuit.
Right: Counter Circuit.

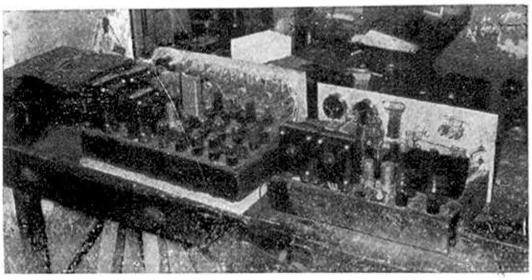

Fig. 8b. Left: Counter Circuit.
Right: Gate Circuit.

Next, the output voltage which comes from the amplifier is fed through the audio transformer to the rectifying circuit of 6H6. We can understand moreover from Fig. 7 that no matter whether the sign of the output voltage coming from the amplifier becomes positive or negative, the voltage which appears at the grid of the next thyratron 66G, is made to show a constantly positive sign, the circuit connection of full wave rectifying being used in the circuit. When the grid voltage is made to be higher than ignition voltage by the output voltage of rectifying circuit, the thyratron bulb ignites immediately. It must be remarked that the output voltage which comes from the rectifying circuit is always accompanied with the voltages caused by the noises of the earth's ground. Therefore, the grid bias voltage of the thyratron must be always regulated to have constantly a suitable value which becomes larger than that of the noise voltage. For it will not, of course, serve our purpose if the thyratron does its action by the disturbance voltages due to noises in the earth. The magnitude of the noises varies always with time and place, and therefore, in respective cases of the prospecting procedure, we must regulate the action level of the thyratron appropriately so that it will not be influenced by the noise voltages.

After the two thyratrons do their actions of ignition for respective signal voltages, respective plate voltages in the parallel circuits are differentiated by passing the circuit with a condenser and a resistor respectively. These two differentiated voltages are successively fed to each grid of the flip-flop circuit of 6SN7 as shown in Fig. 7. By reset switching, the flip-flop circuit is previously set in the state in which the plate in one side of 6SN7 becomes conducting and that in the other side becomes not conducting. Then the voltage of the suppressor grid of the next amplifying bulb 6SJ7 becomes lower, and therefore the amplifying action of it is lost. When the first pulse comes in the flip-flop circuit, a change occurs in the state of the flip-flop circuit and the suppressor grid voltage of the next bulb becomes high and the bulb recovers its function of amplifying. Next, when the second pulse comes in, the state of it returns again to the original one. On the other hand, the sinusoidal waves of 8000 c/s produced by the local oscillator of 6ZP1 are fed constantly to the control grid of 6SJ7. Therefore, the waves of 8000 c/s appear at the plate of this bulb during the time when the suppressor grid attains high voltage.

In order to know the duration time in which the shock makes the action on the first seismometer *A* and next on the second seismometer *B* on the ground, we must count the numbers of the waves which appeared at the output of the bulb 6SJ7 by the next counter chronograph circuit.

4. Apparatus III. Counter Chronograph Circuit.

The diagram shown in Fig. 9 is the circuit of the counter chronograph for the present apparatus, and its practical apparatus is shown in Figs. 8a and 8b. The first bulb of the circuit has an important rôle in making the operations of the next flip-flop circuits smooth and changing the sine wave form of the waves which come from the preceding circuit into square form. Because, in the case of sinusoidal waves of 8000 c/s, the circuits cannot operate owing to their low frequency. The squared voltages are then fed to the series of many flip-flop circuits as shown in Fig. 9. Now, the flip-flop circuit used for the present apparatus becomes Higinbotham's[2] "scale of two" circuit. The action of the series of the first three steps of these is to reduce the 8000 c/s scaling down to 1000 c/s. Beside these series, there are two groups which are constructed by four "scale of two" circuits. These are "scale of ten" circuits modified

2) W. A. HIGINBOTHAM, *R.S.I.*, **18** (1947), 706.

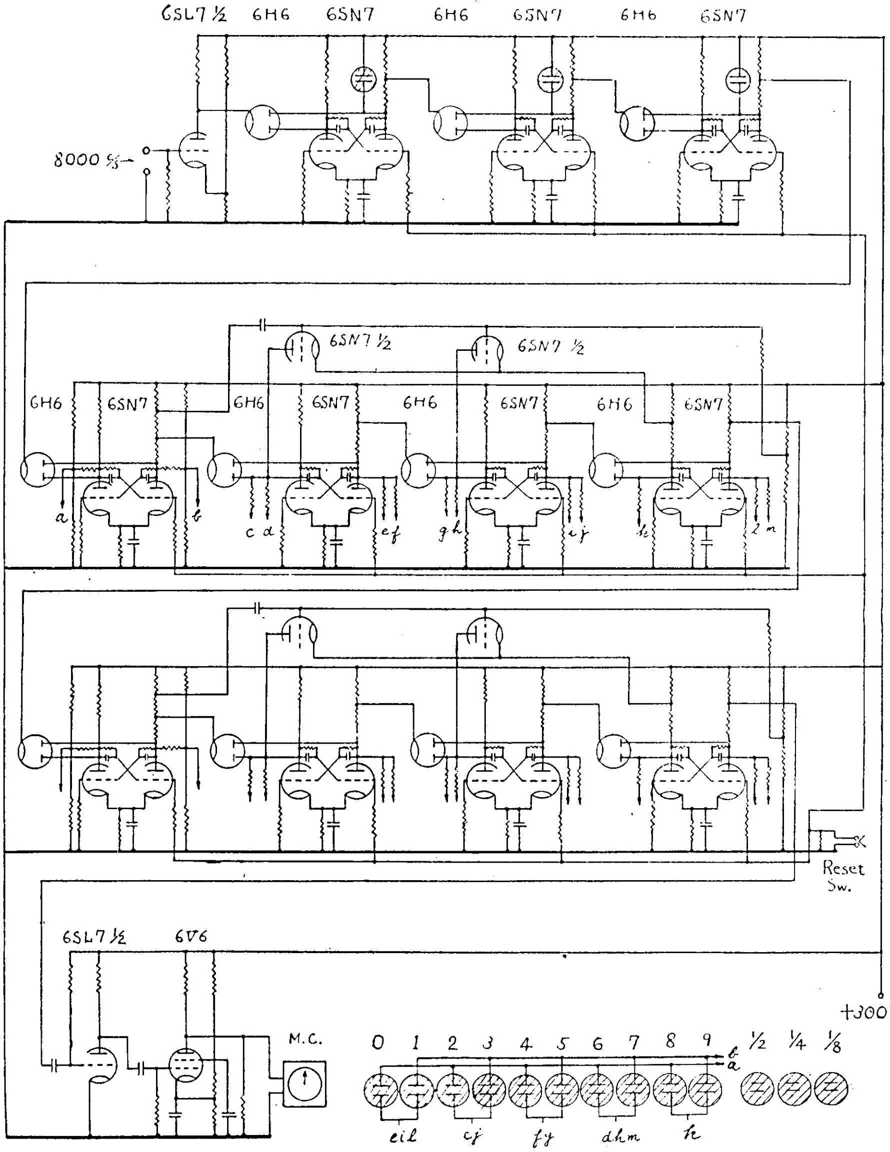

Fig. 9. Counter Chronograph Circuit.

by the "scale of sixteen" by the leap phenomena, in counting, produced by the two triods as shown in Fig. 9. By the two "scale of ten" circuits above mentioned, the square waves of 1000 c/s is reduced to those of 10 c/s.

By these procedures, the states of all flip-flop circuits are varied favourably in accordance with the numbers of fed pulses of square waves, and henceforth the numbers which show the time duration, are instantly indicated by the twenty-three neon tubes connected suitably to the present circuit. These neon tubes are schematically shown in the last line in Fig. 3. In the circuits connected as shown in Fig. 9, three neon-tubes indicate 1/8, 1/4 and 1/2 milli-seconds, and ten neon-tubes indicate respectively the numbers of 1 milli-second order, and also another ten the numbers of 10 milli-second order respectively. By these procedures with this counter chronograph circuit, we can actually and easily read the numbers of the fed pulses which come from the gate circuit. For instance, in the last line in Fig. 3, if we assume that the shaded four neon tubes are lightened by the fed pulses, we can immediately read that the time interval of the fed two pulses becomes 32 and 3/8 milli-seconds.

For the time intervals which becomes longer than 100 milli-seconds, this circuit repeats the operation of the same procedures as already discussed, so that the mechanical counter is able to indicate the repeated numbers. The circuits composed of the bulbs of 6SL7 and 6V6 are made to drive the mechanical counter.

For this counter chronograph, the time is measured at an accuracy of 1/8000 seconds, because the frequency of the local oscillator becomes 8000 c/s for the present case. Therefore, if we want to change the accuracy of the counter, it may be done by changing the frequency of the local oscillator. In the actual case of the prospecting of detecting the rather shallow layers, we think that it is suitable to use the frequency of 8000$\sim$1000 c/s as the time scale.

5. Experiment.

The experiment with the present new-designed prospecting apparatus was carried out at the ground in front of the Department of Geophysics, Faculty of Science, Univ. of Tokyo. At this ground, the seismic prospecting by ordinary method with electro-magnetic oscillograph has already been done by some investigators, and therefore the structure of the earth's surface under this ground is somewhat clear.

The two new-designed seismometers were also set on the ground, and one of them was set of course very near the place where the artificial shocks were given. Before the commencement of the measurement proceeding, both the gains of the amplifier and the grid bias of the thyratron were regulated to secure the state in which the thyratron grid voltage becomes a little higher than the noise level of the ground under prospecting. We then closed the "reset switch". Then, the state of the flip-flop circuit in the gate circuit became normal and the twenty three neon lamps indicated zero. Hereby, we made the complete preparation for the measurement procedure. At a signal to produce a shock on the ground surface, a steel ball filled with lead weighing the 40 kg, was dropped from a suitable height as shown in Fig. 10. Then the set of the neon-tubes of the counter chronograph instantly showed the time interval needed for the shock travel between the two seismometers on the ground. By this procedure, varying the distance between the two seismometers, we were able to obtain the data in Table I quickly and easily. Therefore the "time-distance curve" were obtained from Table I as shown in Figs. 11 and 12, in which the unit of ordinate becomes 10^{-2} sec., and that

Fig. 10. Shock Generation Device With Ball.

Table I. Indication of neon lamp.
(Data A & B show in Figs. 11 and 12 respectively.)

Distance (m)	Data A (milli-sec.)	Data B (milli-sec).	Distance (m)	Data B (milli-sec.)
3	21, 22, 23, 25 30. 32	20, 22	22	84, 86
4	29, 30, 31	26, 27, 27, 29	24	87, 87
5	36, 36, 37	28, 30, 31, 33	26	89, 92
6	39, 40	32, 35, 37, 37	28	85, 86, 90, 94, 96, 101
7	43, 43, 44, 52, 53		30	95, 97, 104, 106
8	48, 48, 49, 56	39, 43, 44, 47	32	92, 93, 104, 109, 114
9	50, 51, 51, 52	41, 47, 48, 49		
10	54, 55			
11	57, 57, 58	49, 51, 54		
12	62, 63, 63			
13	65, 67	63, 63		
14	68, 69, 70, 75			
16		72, 73		
17		78, 79		
18		80, 81		
19		82, 82		

of abscissa is shown in meter. Of course, these two Figures are taken from two respective measuring lines on different days. As Fig. 12 shows, at the distances far from the shock origin, the points showing the

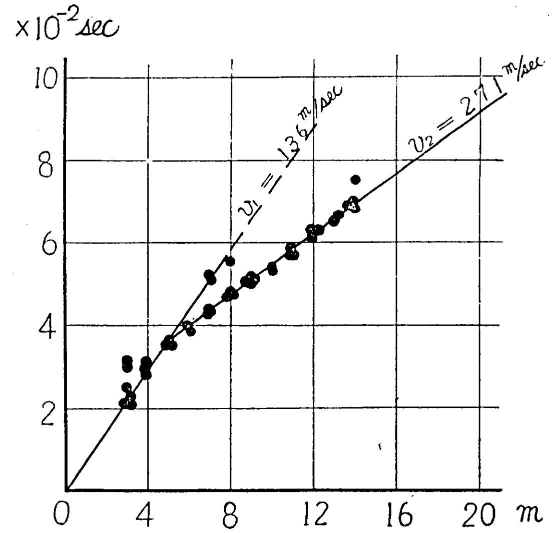

Fig. 11. Time-Distance Curve.

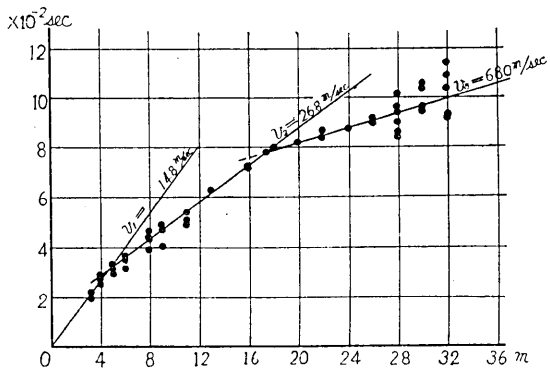

Fig. 12. Time-Distance Curve.

measured time tends to scatter and it becomes somewhat difficult to determine exactly the "time-distance curves" for these points. The reason for the occurrence of this phenomenon, perhaps, is as follows: The magnitude of the noise voltage at this ground becomes comparable with that of the threshold voltage due to the shock wave at the locality distant from the shock origin, and also at times the thyratron *B* in

Fig. 7 does its action for another shock of unknown origin different from the shock wave excited by the experimented shock origin. From these facts, therefore, it must be remarked that in case of distances far from the shock origin, we must use a somewhat large energy of shock. For obtaining a large energy of shock, the general course is to increase the falling velocity of the dropped weight or use a favourable dynamite. At the moment when the weight parts from the weight hanger, the reaction is suddenly excited in the hanger frame. This reaction through the frame will be propagated in the ground faster than the shock wave excited by the dropped weight. Therefore, we must arrange seismometer, which is set very near the shock origin, so as not to be excited by this reaction. The detailed discussions for the influence of this reaction on the seismometer's action will be postponed to the next report. From the data shown in Figs. 11 and 12, assuming that the layer becomes parallel to the surface of the ground, we are able to determine the depth H of the first layer to be about 1.4 meters[3]. The results obtained so far by this present apparatus seems not to be different from those obtained by other methods.

6. Conclusion and Acknowledgement.

The present study of the prospecting with this new-designed apparatus shows that the present apparatus may be of some use in actual seismic prospecting. This instrument, however, is only a trial and therefore it contains some deficiencies to be improved. Moreover, in order to develop the availability of this apparatus, we must compare the results obtained at various localities with those obtained by other methods such as the boring method.

It must be added that since the present apparatus is combined with eliminater type of A. C. source, it cannot be used in localities with no A. C. source. The report of an apparatus favourable for D. C. source with the experimental results shall be given in the next occasion.

In conclusion, we must express our sincere thanks to Mr. Shigematsu Ito and Mr. Yoshiro Komatsu of the Ministry of Agriculture and Forestry who suggested the necessity of the present study to one of the present writers and made every exertion in obtaining some expenses for the present study. The authors also express hearty thanks to Mr. Torawo Yamazaki of the Shimada Rika Industry Company, Ltd., who also

3) From Fig. 12, we obtained the following results: The thickness of the first layer = 1.3 m, and that of the second layer = 2.7 m.

suggested the necessity of the present study and encouraged the writers during the course of the present investigation.

30. 簡易弾性波式地下探査装置の研究

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電源開発，農耕用水，上水道，工業等の用水の調節など，水の合理的な利用開発のため，今全国各地で，ダムやトンネルの建設が盛に行われている．

そこで，其等の工事の基礎となる地盤の様子を知る事が重要になるのであるが，此の目的には色々な方法が用いられている．

直接的には，ボーリングを行つて調べる事が出来るが，経済的理由から種々の，間接的方法で推定する事が行われている．茲に所謂弾性波式地下探査法は間接的方法の一種である．

之は二つの換振器（地震計の一種）をある距離だけ隔てておき，一方の換振器の近くで地面に衝撃を与えて，弾性波を起すのである．此の弾性波が，換振器から換振器迄伝わるに要する時間を距離の函数として，測定し，時間と距離とのグラフ（走時曲線）から地表下にある幾つかの地層の位置や状態を理論的に推定するのである．

従来は，此の場合の時間測定の方法として，電磁オスシロを用いて感光紙上に現れた記録のうち，一方の初動から他の初動迄の時間差を読みとつたのであるが，実際は可成り手数が，かかる上に，初動以外の記録は不必要である．

本装置では此の操作を，両換振器からの初動だけを捉えてエレクトロニツクスを応用した真空管回路が，自動的に働いて，呉れるので，非常に簡単化された．茲に本探査法の特徴を従来のものと比較して列挙して見ると次の如くなる．

表 1

従来の装置	新しい装置
1回の実験に時間を要する．	短時間ですむ．
1回の実験に要する経費が割合に多い．	経費が要らぬ．従つて回数を増し誤差を少くする事が出来る．
実験にかなりの人数を要する．	最小限二人で済む．
初動を写真現像で読む装置に非常な経費を要する．	此の操作がない．装置の経費は従来のものの $^1/_{10}$ 以下．
全装置は可成りの容積になる．	割合に小型である．

弾性波が通過するに応じて，近い方からA，Bなる二つの換振器が動かされて，それぞれの端子に相次いで第3図に表わされたような形の電圧を生ずる．之等の電圧は別々に次の増幅器A及びBに入つて増幅され，更に整流回路に入る．茲で整流された電圧が次のサイラトロン回路に入ると，急に放電電流が流れてパルスを生ずる．

之等のパルスが第3図に表わされているが，此のパルス間隔が波の通過時間を表わしているのである．

此の二つのパルスが次のフリツプフロツプ回路に相次いで入ると，初めのパルスで電圧が上り，次のパルスで元に戻つて，第3図に表わされるような矩形電圧が出来る．

一方，発振器から 8000 サイクルの電流が常時，時限増幅器に入つているのであるが，此の増幅器は，矩形電圧の間だけしか，増幅作用が無いようになつているので，此の矩形の枠に入るだけの波数が増幅されて出て来る．

8000 サイクルの交流は丁度，二つのパルス間隔を測る物指しになるわけで，増幅されて出て来た波数を数えれば時間が判る事になる．

次のカウンター，クロノグラフは，此の波数を数えて，指示する装置である．

指示は第3図に示したように，10 桁を示すネオン管が 10 個，1 桁のが 10 個，$^1/_2$ を示すものが 3 個総計 23 個のネオン管があつて，例えば，第3図のネオン管に於て斜線をしたものが点いている時には $32^3/_8$ ミリ-セコンド，と容易に時間々隔がわかる．

次に各ブロツクの働きを稍詳細に述べる事にする．

(イ) 換 振 器

弾性波が来ると換振器は第3図で表わされるような揺れ方をするのが普通であるが，此の場合必要なのは，最初の波の立上りだけである．

而も初動の立上りが，急激である方が時間測定の誤差が少くなるので，玆で用いた換振器は第4図及び第5図でみるように，斯様な点を考慮し，且感度が大になるように設計された．

之は従来の電磁型換振器が普通，磁石が固定していて，可動線輪が振子に直結していただけであるのに較べて，磁石自身が振子の質量 (3 kg) になつて居り，此の振子の振動はエデンバネ機構で拡大されて，可動線輪の動きとなるので，感度は一般の電磁型換振器の 10 倍程度になつている．

尚此の場合可動線輪の質量は 16 gr であつて，エデンバネは幅 0.35 mm，厚み 0.1 mm，長さ 12 mm の燐青銅の板を用いた．線輪は B.S. 48″ のエナメル銅線を 7000 回巻き，其の直流抵抗は約 2000 Ω である．振子と可動線輪の質量比 μ は此の場合 $^{3000}/_{16}$ となるので，基本倍率 V と幾何倍率 V_G との関係式

$$V=\frac{V_G}{1+\dfrac{V_G^2}{\mu}}$$

から V と V_G との関係を求めると第6図の曲線が得られる．

此の曲線から基本倍率が最大になるように幾何倍率を定めると $V_G=13.6$，$V=6.9$ を得た．斯様にして，設計，製作したものは，写真に示されていて，固有振動数，毎秒 37 サイクルで速度振幅 1 粍毎秒 5 Volt の電圧を生ずる．

(ロ) 増幅器回路

6SJ7 及び 6J5 を用いた二段増幅である．

2 個の可変抵抗を用いて，調節が出来るようになつている．

(ハ) 整 流 回 路

6H6 を用いた両波整流方式である．初動が ＋ で来ても － でも正の電圧が起るようになつている．

(ニ) サイラトロン回路

予めサイラトロンのグリツドは直流の低い電圧に保つておくが，整流された正の電圧が入つて来て此の電圧を放電電圧以上に上げると，プレート電流が流れる．

最初の直流電圧の定め方は，測定地によつて条件が異るので，第7図の可変抵抗器を調節して，サイラトロンが放電しない最大限の値に其の都度定める事が出来る．

サイラトロンが放電して，生じた電圧は小容量のコンデンサーを通ると微分されてパルスになり次のフリツプ-フロツプ (Flip-Flop) 回路に入る．

(ホ) フリツプ-フロツプ回路

双三極管 6SN7 を用いた．此の回路はトリツガー，アムプリフアイヤーとも云われ，お互いのプレートとグリツド同志が結合されているので両方に等量の電流が流れると云う事は不安定のため起り得ない．安定に存在するのは一方が流れて，他方は流れないと云う状態で,流れている方のグリツトに負のパルスを入れてやると，状態が反転する．

始め，リセツトスイツチを押して第7図の右側真空管が流れている状態にしておく．

従つて，プレート電圧は低い値になつている．此のグリツドに負のパルスが入ると状態が反転するので，プレートの電圧は上るが，次のパルスが反対のグリツトに入るに及んで，状態は元に戻るので，電圧も下り第3図に示めしたような，矩形電圧を生ずる事になる．

(ヘ) 時限増幅器

前のフリツプ-フロツプ矩形電圧が此の増幅管 6SJ7 のサプレツサー，グリツドに入ると，高い電圧の場合にだけしか増幅作用がないので，常時コントロールグリツドに入つている発振器からの 8000 サイクル交流は第3図の矩形枠の時間だけ増幅されて，次にもう一度，6SJ7 で増幅された後，カウンター，クロノグラフ回路に入る．

(ト) カウンタークロノグラフ回路

第7図に示されているように，カウンタークロノグラフ回路はフリツプフロツプ回路が単位になつていて，何段にも重なつている．前に述べたように，フリツプフロツプ回路は 2 個のパルスに対して 1 個の矩形波を生ずるので，最初の双二極管 6SN7 三段で 8000 サイクルは 1000 サイクルになる．

奇数のパルスはネオン管に指示される．

次に一双づつ，4 個並んだ 6SN7 は 10 進法回路である．

元来フリツプ，フロツプを 4 個使うと 2 の三乗即ち 16 分の 1 に周波数が落ちるのであるが図の上の方にある双二極管 6SN7 が状態を 6 個だけ跳ばす役目をして，丁度 10 個に 1 個の割合で周波数が落ちるようになつている．之等の真空管の各プレートを第 9 図の右下に示すように 10 個のネオン管に結合すると，例えば 6 個のパルスが来た時には 6 を示すネオン管が点いて，他は全部消えるようになるので，読取りが極めて簡便，容易である．

10 進法の回路はもう一つ重ねられている．

之等の回路によつて，8000 サイクルの交流は始め3個のネオン管で $1/8 \times 10^{-3}$, $1/4 \times 10^{-3}$, $1/2 \times 10^{-3}$ 秒を読み次の 10 進法で 10 milli-second 迄，もう一つの 10 進法で 100 milli-second 迄読みとられるわけである．

それ以上に長い時間は，指示が繰返しになるので繰返しの数はメカニカル，カウンター (M.C.) が指示して與れる．

6SL7 及び 6V6 の回路はメカニカルカウンターのドライバー回路である．

操　作

実際に使用する場合には先づサイラトロンのグリツド電圧をノイズ状態に応じて適当に調節しておき，SW を入れてサイラトロンプレートに電圧を与える．

次にリセツトスイツチを押すとフリツプフロツプ回路が正規の状態をとると同時にカウンタークロノグラフは零を指示する．

此のようにして，地面に衝撃を与えると直ぐに時間がネオン管の点滅から読みとれる．

実　験

東京大学地震研究所 2 号館前のテニスコート附近でテストを行つたがその際に得られた実験結果を第11図及び第12図に示した．

換振器 B を A に近いところから或る間隔おきに遠ざけて行つて，各々の距離について 4～5 回時間測定を繰返した．

図に示されているように近い距離では測点が割合いにかたまつて出るのに反して，遠方になると，稍，散らばる傾向がある．

遠方では初動が小さくなるため，時間が短かく指示される事もあるし，或は初動が小さくて，ノイズと同程度以下であると，時間が長く指示される事もあり得るのである．

然し乍ら斯様な難点は衝撃の与え方を大きくする事によつて楽に解決出来るのであつて，此の実験では一応或る距離迄繰返し測点がとれて割合確からしい走時を決定する事が出来ると云う事を強調したい．

之等の據つた点を結ぶと数本の直線の上に載つて居る事が明瞭にわかる．

各直線の傾斜は，各層の速度を表わすのでは，層が存在している事が明かである．

之等の直線群から各層の深さが計算出来る．例えば第11図で上層の速度から順次 v_1，v_2 とし，v_1，v_2 を表わす直線の交点の距離座標を Z とすると上層の厚み H は次式

$$H=\frac{Z}{2}\sqrt{\frac{v_2+v_1}{v_2-v_1}}$$

によつて算出される．

この場合 $H=1.4\,\mathrm{m}$ である．

第12図の場合は表層の厚みが 1.3 m 第二層の厚みは 2.7 m となる．

此の実験で行つた衝撃の与え方は第10図に示されているように，櫓を組んで，40 kg 程度の鉄球を懸垂装置で吊り上げ，落下させるには電気的にスイツチを働かせて遠隔操作が出来るように，なつている．

鉄球が地面を打つ前に，懸垂装置を離れる時，生ずる衝撃が櫓を伝わつて先に地面に走るので，際の衝撃波の前に換振器が揺れてしまう場合がある．

之を防ぐには櫓の柱をバネの上に浮かせて，鉄球が離れる時に生ずる衝撃を，小さくするようにして，実験した．

猶近い点を測定する場合には櫓を用いずに手で持ち上げて落す程度で充分である．

結　言

此の実験によつて，地下 10 m 程度迄は簡単に而も費用も要せず測定出来る事がわかつた．

例えば第11図に表わされた測点をとるのに約30分内外で完了するのである．

一つの測点を定めるのに此の方法によると十数秒で済むのであるが従来の方法では写真現像や色々な操作を含めて一時間程度は必要である．

茲で用いた電気装置はエリミネーター式であつて，交流電源のない山の中などでの探査実験には適さないので電池式電源に改良すれば其の他に増幅感度もより以上に増大出来よう．

猶，装置をポータブルにして，搬送に便利な設計を試たみいと思つている．