July 23, 1957 B. D. LEE **2,800,639**

METHOD AND APPARATUS FOR ANALYSIS OF SEISMOGRAPHIC RECORDS

Original Filed March 28, 1950 4 Sheets-Sheet 1

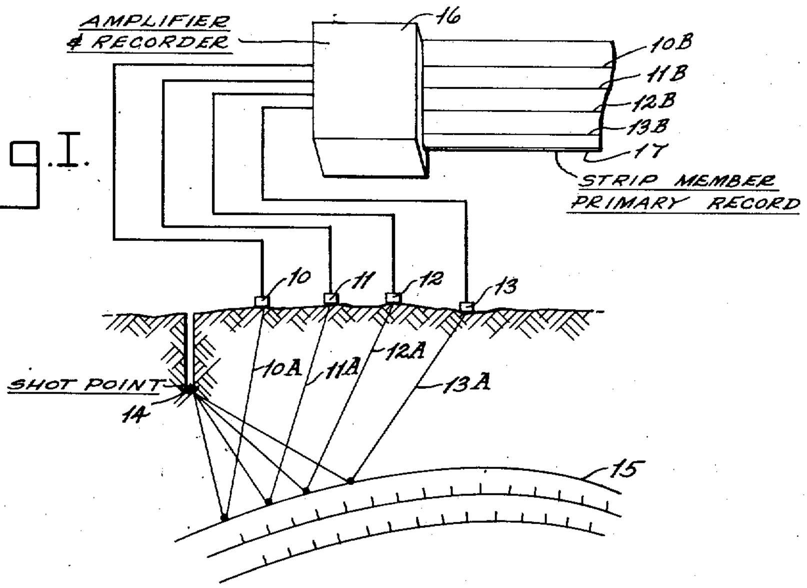


Fig. I.

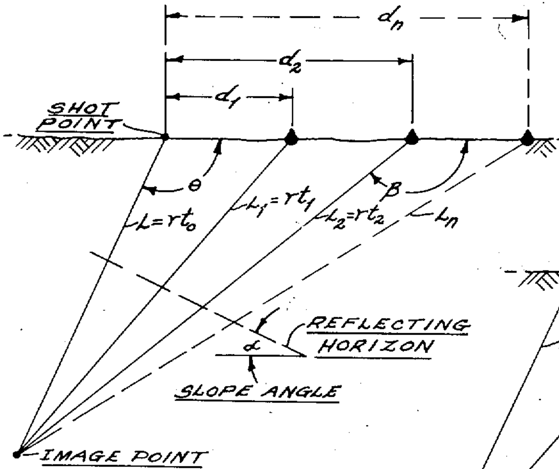


Fig. II.

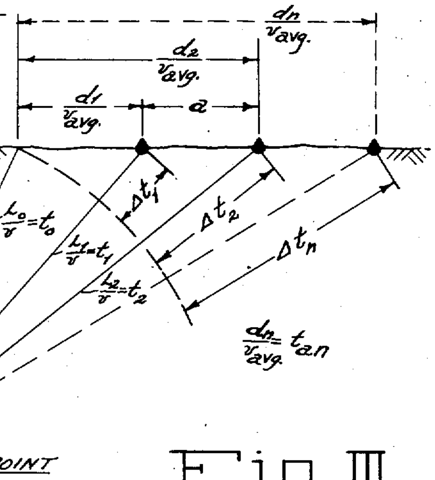
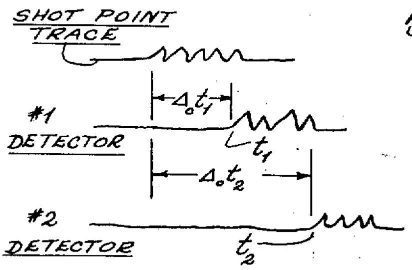


Fig. III.



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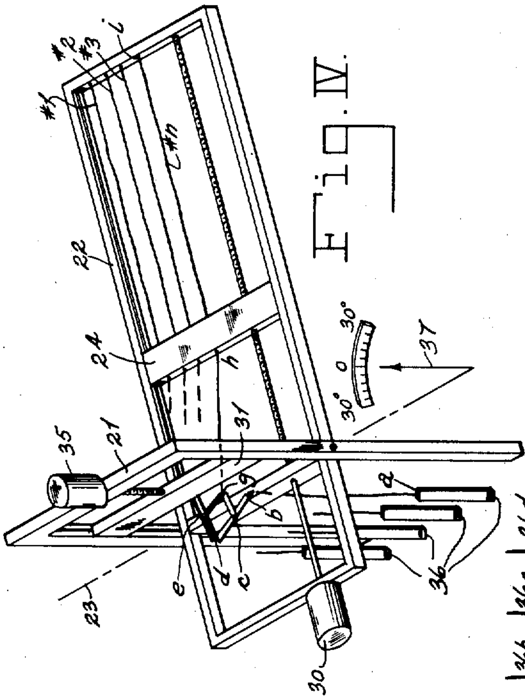

Fig. IV.

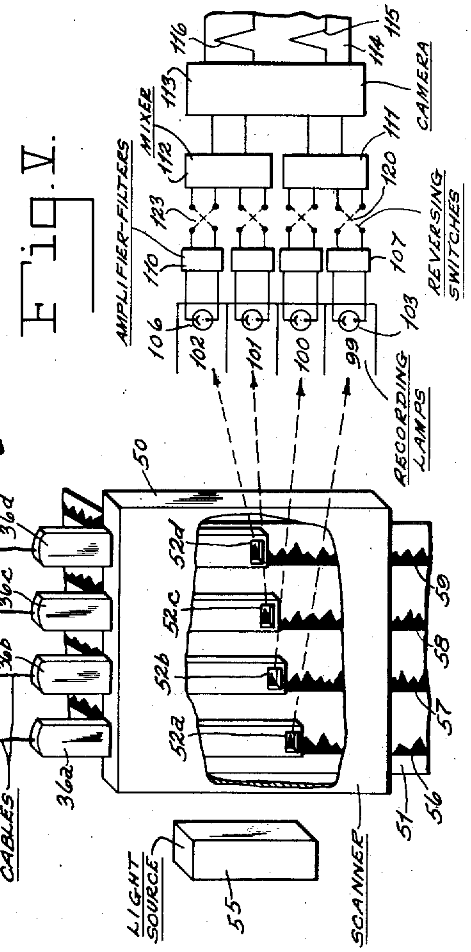

Fig. V.

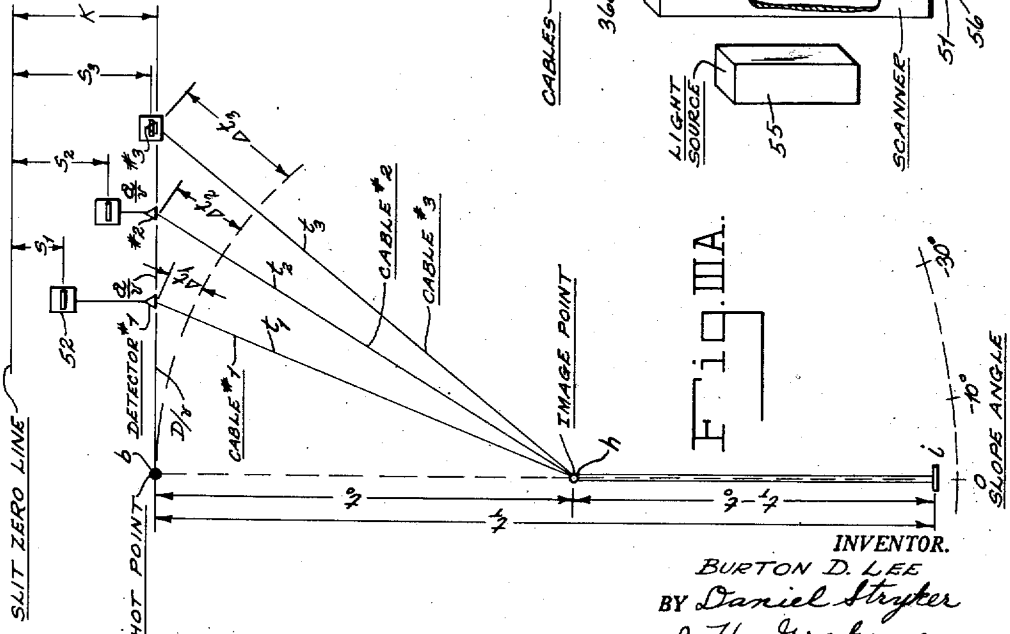

Fig. IIIA.

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METHOD AND APPARATUS FOR ANALYSIS OF SEISMOGRAPHIC RECORDS

Original Filed March 28, 1950 4 Sheets-Sheet 3

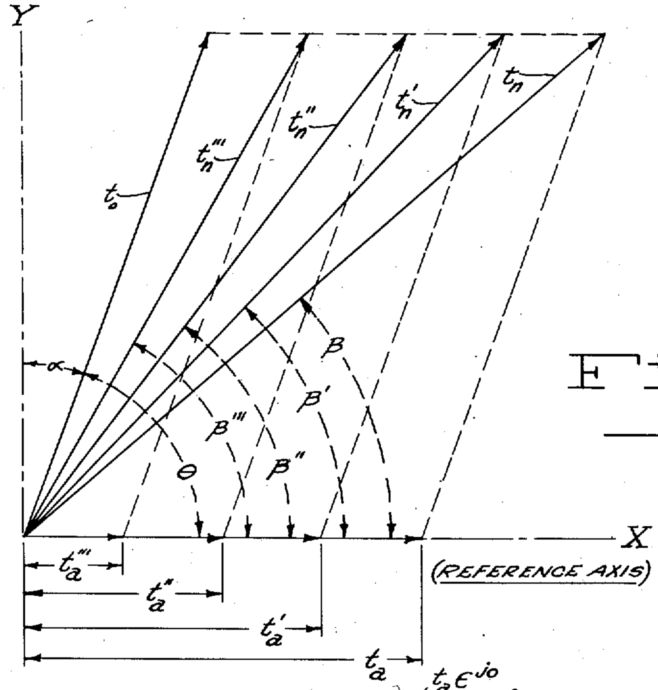

Fig. VI.

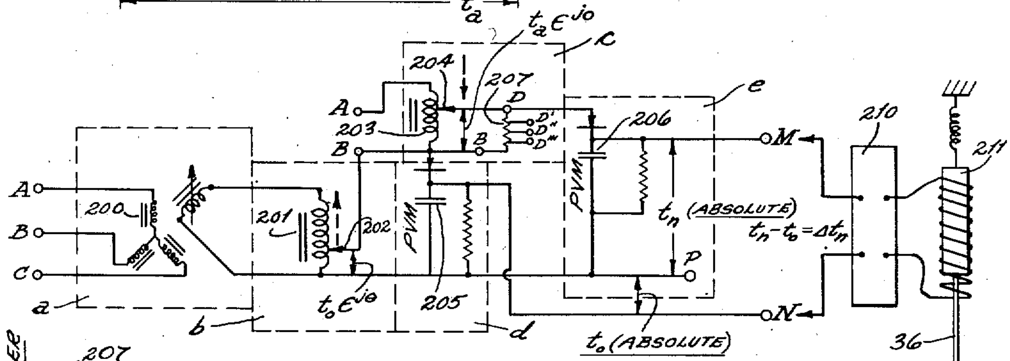

Fig. VII.

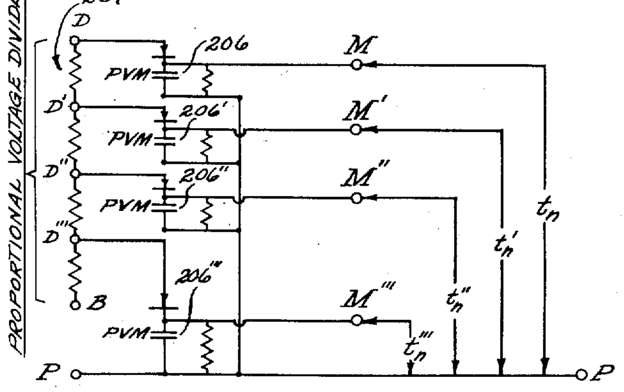

Fig. VIII.

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July 23, 1957 B. D. LEE **2,800,639**

METHOD AND APPARATUS FOR ANALYSIS OF SEISMOGRAPHIC RECORDS

Original Filed March 28, 1950 4 Sheets-Sheet 4

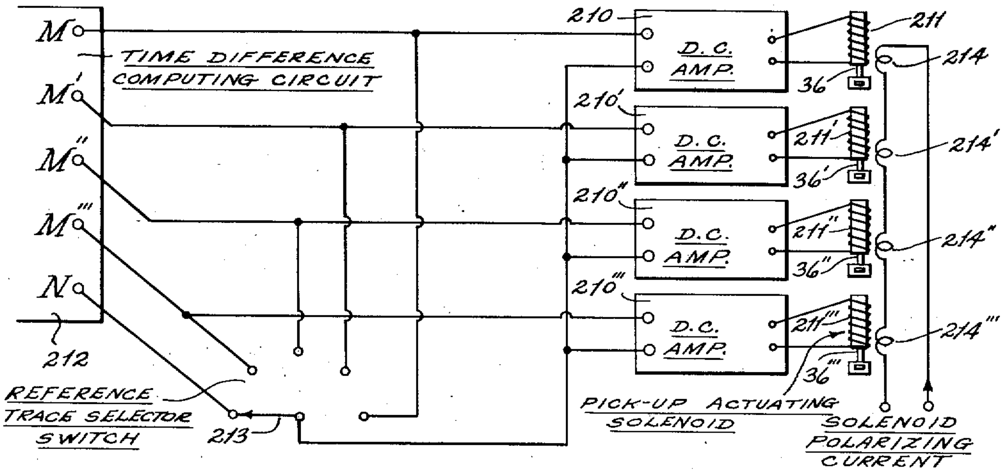

Fig. IX.

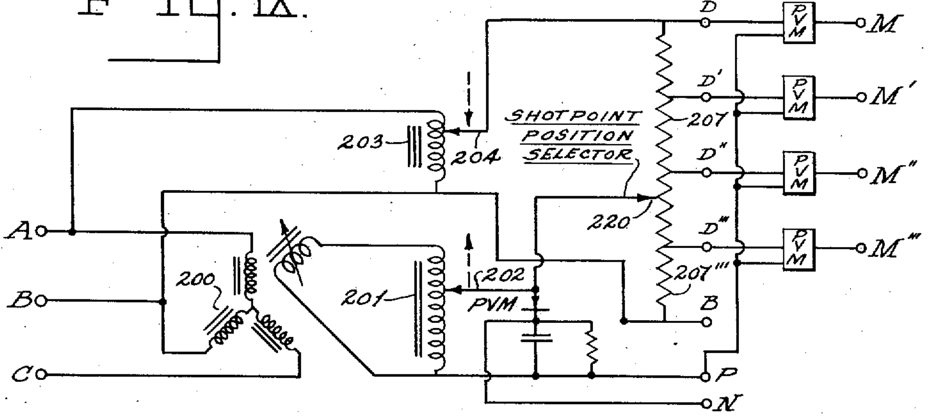

Fig. X.

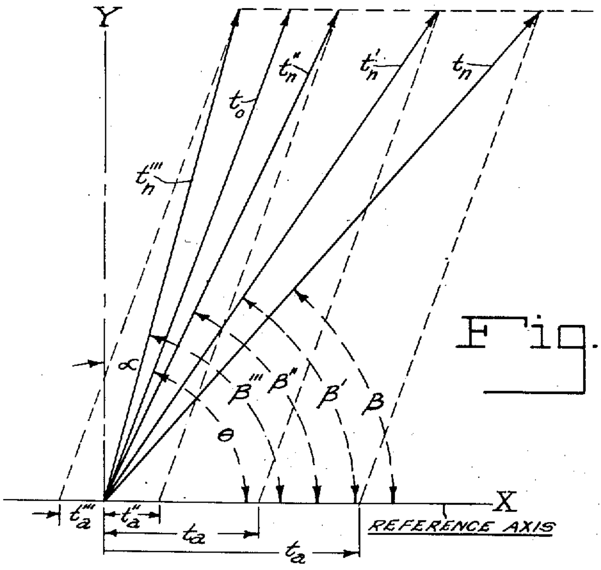

Fig. XI.

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United States Patent Office

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METHOD AND APPARATUS FOR ANALYSIS OF SEISMOGRAPHIC RECORDS

Burton D. Lee, Houston, Tex., assignor to The Texas Company, New York, N. Y., a corporation of Delaware

Continuation of abandoned application Serial No. 152,443, March 28, 1950. This application December 28, 1953, Serial No. 400,620

16 Claims. (Cl. 340—15)

This invention is concerned with seismic prospecting and especially with reflection seismograph practice wherein vibrations are induced in the earth from a shot point, resulting vibrations are detected by seismometers at a plurality of points differently located relative to the shot point and outputs from the seismometers are recorded simultaneously as separate traces side by side on a strip member.

The present application is a continuation of my application Serial No. 152,443 filed March 28, 1950, for "Method and Apparatus for Analysis of Seismographic Records," which, now abandoned, in turn, was a continuation-in-part of my application Serial No. 141,689 filed February 1, 1950, for "Method and Apparatus for Analyses of Seismographic Records." The last named application having been abandoned in favor of a continuation application Serial No. 412,909, filed February 26, 1954, but carrying the effective date of its original, i. e. February 1, 1950, and now issued as Patent No. 2,732,025 on January 24, 1956.

The invention described in the aforesaid continuation-in-part application involves reproducing an adjusted wave record from the aforementioned strip member wherein each is individually and continuously adjusted for its phase-time relation with respect to the phase-time of a reference trace obtainable by a seismometer located at or near the surface of the earth above the shot point, whereby the phase-time of the adjusted traces is made to coincide completely or substantially completely with that of the reference trace.

The invention of the present application involves continuously computing the time differences and continuously effecting the necessary adjustments during the reproduction, utilizing an electrical means, as will be described in more detail later.

In calculating results from reflection seismic records, it is frequent practice to use the trigonometric formulae governing the wave path diagram shown later in Fig. 11. There are some simplifying assumptions involved in the assumption of straight line wave travel paths but such assumptions are, in most cases, acceptable since errors introduced thereby are quite insignificant. It is necessary in the calculation that wave velocity be known and expressible as some function of time of arrival of reflections.

Given the depth and slope angle of a reflecting bed and the average wave velocity it is possible to compute, first, the lengths of the wave travel paths to the various seismometers and, second, the reflection arrival times by dividing path length by velocity. The problem involved in reflection seismic propspecting, however, is the inverse of that just stated. The reflection record furnishes only the reflection arrival times at known distances from the shot point. From this information one may reconstruct the wave path diagram if, again, velocity is known.

It is frequently desirable to "mix" the output of two or more spaced seismometers in order to accentuate reflections which are of necessity recorded in conjunction with random disturbances and other undesired waves.

Reflections can best be accentuated when they arrive in time-phase coincidence on the signal channels whose outputs are being "mixed." Usually, such coincidence does not exist. In fact, it is possible that a reflection may arrive on adjacent channels in phase-time opposition with the result that "mixing" obscures rather than accentuates the desired reflection with consequent loss of data which should have been available from the record. If one knew prior to recording a shot that a certain reflection would arrive at the seismometers with a specific time-phase relationship, it would be possible to introduce corrections into the original record so as to achieve the desired coincidence of time-phase and thus accentuate that reflection. Taking such a shot would be futile, however, for if one knows the results beforehand he has already all information to be gained from the shot.

A more fruitful approach to the problem is to record in reproducible form on a common strip member the individual uncompensated outputs of the separate seismometers and later scan this record for all reasonably possible conditions of time-phase relationships. This would be accomplished by repeatedly reproducing the original record with pickup points compensated for the time differences which would exist under successively changing assumptions as to dip of reflecting strata. From this group of records one could more readily recognize reflections which arrive in substantial time-phase coincidence, particularly if "mixing" is used in the reproduction of the record.

If such a procedure is to be carried out in an efficient manner, continuous correction of the pickup points at all times during reproduction of the record is a necessity. It is the purpose of this application to disclose method and means for continuously computing and displaying or effecting the required corrections.

In further description of the invention, reference will be made to the drawings.

Figure I illustrates schematically the production of a seismic record on a strip member.

Figure II is a space diagram showing the relationship between a sound wave moving from the shot point downward in the earth and being reflected from the top of a formation to each of three detectors on the surface of the earth.

Figure III is a time diagram illustrating the way in which the space diagram of Figure II can be converted into a diagram whose dimensions are time functions.

Figure IIIA and IV illustrate one embodiment of a mechanical means for continuously computing phase-time differences.

Figure V illustrates schematically a scanner provided with adjustable slits, the adjustment of which is controlled by the mechanism of Figure IV. In addition, it shows schematically means for reproducing an adjusted wave record on a secondary strip member.

Figures VI to XI inclusive, explain and illustrate an electrical method of continuously computing phase-time differences.

Since times and time differences are the basic data recorded, corrections to these data must be in the nature of time corrections. Wave path diagram, Figure II, however, is a distance diagram which does not readily lend itself to the direct solution of the equations determining these time corrections. Transformation of the wave path diagram to a time diagram, Figure III, by division of all components of Figure II by wave velocity results in a solution of the diagram directly in terms of time and time differences.

It is apparent from Figure III that an analogue computer could be built with the time diagram as its basis. It is to be noted that the transformation from Figure II to Figure III produces a system of triangles in which all sides are variables while only two sides of the triangles of Figure II are variable. Both of the variable sides of Figure II are nonlinear with respect to time unless velocity is constant. The element representing the path of the image point in Figure III is linear with respect to time while the other two sides are nonlinear. The effective detector position of Figure III is proportional to the real distance of the detector from the shot-point, which is a constant, and inversely proportional to velocity which is expressible as a function of time.

Since one purpose of the solution of these diagrams is to obtain the time differences between the various traces and a reference trace at the shot point, the step of subtracting the time of arrival of a reflection at the reference detector from the times of its arrival at the various other detectors must be performed. Figure IIIA shows schematically one form of device (illustrated structurally in Figure IV) which will produce results proportional to time differences between traces, it being understood that the distances D/v and a/v are variable with time and that special means for linking the cables to the slits are required though, for simplicity, not shown.

Referring to Figure I, the numerals **10**, **11**, **12** and **13** designate seismometers placed in a line on the surface of the earth extending out from a shot point **14**. Seismic waves generated at the shot point are reflected from a formation interface **15** below the surface of the ground, say at an interface at which seismic velocities change greatly. Sound waves **10A**, **11A**, **12A** and **13A** are reflected from the horizon and picked up by the respective seismometers. Currents varying in accordance with the variations of the received waves are carried from the individual seismometers to a multiple amplifier and recorder **16** from which a reproducible primary record on a strip member **17** is formed.

Reference is now made to Figure II. As previously mentioned, this diagram shows the relationship between a sound wave moving from the shot point downwardly in the earth and being reflected from the top of a formation to each of three detectors located on the surface of the earth.

As is known, the reflected sound wave appears to come from a point known as the image point which lies as far below the reflecting surface as the shot point above the reflecting surface and located on a normal line from the shot point to the reflecting surface. The distance from the shot point to the image point, L_0, is equal to the velocity of the sound, v, times the time t_0. Likewise, the distance from the image point to the first detector L_1, is equal to vt_1, and the distance to a second detector vt_2. The distance from the shot point to the first detector is d_1 and to the second detector is d_2, while distance to the nth detector is d_n.

As known, sound recording is frequently done with 12 detectors, one at the shot point, the other 11 with regular spacing between each detector.

The lower portion of Figure II shows typical traces for detectors **1** and **2** and for a detector at the shot point. It will be noted that the arrival time at the second detector lags the arrival time at the shot point detector by an interval Δt_2.

The objective of this invention is to solve the triangles of the space diagram in Figure II in such a way as to obtain differences in path lengths $L_0, L_1, L_2 \ldots L_n$ and, finally, to convert these differences to time differences which may be used to align the pick-ups of the reproducer so as to eliminate the differences in arrival times which are inherent in conventional records.

Figure III illustrates the way in which the geometric pattern developed in Figure II can be converted into a diagram whose dimensions are time functions. Inasmuch as the average velocity of sound through the earth is a function of time, the time diagram can be developed by simply dividing all sides of the similar triangles in Figure II by the average velocity v_a. When this is done, the distance from the shot point to the image point and the distances of the reflected sound path to each of the detectors are functions of the time alone and the spacing between detectors is

$$\frac{d}{v_a}$$

which is a function depending entirely upon geometrical spacing and the average velocity of sound.

The foregoing transformation of the space diagram into a time diagram is a valid step because given an equation $y=f(x)$, multiplying or dividing both sides by the same quantity does not destroy its validity. Thus $my=mf(x)$, also

$$y/m=\frac{fx}{m}$$

In the foregoing diagrams the velocity is a function of time, i. e., $v=f(t)$.

Frequent practice in seismographic exploration by the reflection method is to assume a velocity function of the form:

v (average)$=v_0+at$ where v_0 and a are determined experimentally in the area being explored. For example, a detector may be lowered into a bore hole to different depths. Shots are fired at or near the surface. The wave transit time from the shot point to the detector at each depth is measured and from the information so obtained the velocity function is determined. In the foregoing equation v_0 is the velocity in feet per second at zero time after the shot and t is the time in seconds required for a wave to travel from the shot point to the reflecting horizon and back to the surface of the earth.

However, it is contemplated that the velocity function may be any other functional form, the only limitation being that it is a single valued and positive function of time and that a derivative exists at all points.

In the coastal areas v_0 is usually about a lower limit of 5000 feet per second while (a) has a value of approximately 1000. Substituting these values in the velocity function, the equation becomes

$$v \text{ (average)}=5000+1000t.$$

In the space diagram of Figure II, taking the case where the angle θ is 90 degrees;

$$L_1^2=L_0^2+d_1^2$$

Therefore

$$L_1=\sqrt{L_0^2+d_1^2}$$

Also

$$L_0=vt_0 \text{ and } t=L/v$$

While

$$\Delta t=\frac{L_1-L_0}{v}$$

and d_1 is assumed to be 500 feet.

Using the space diagram, Δt can thus be determined from the space diagram as in the following examples where t is taken as 0, 1 and 2 seconds, respectively:

Table I

t	0	1	2
v	5000	6000	7000
L_0	0	6000	14000
d_1	500	500	500
L_0^2	0	36×10^6	196×10^6
d_1^2	25×10^4	25×10^4	25×10^4
$L_0^2+d_1^2$	25×10^4	3625×10^4	19625×10^4
$\sqrt{L_0^2+d_1^2}$ (or L_1)	500	6020.797	14008.925
L_1-L_0	500	20.797	8.925
$\frac{L_1-L_0}{v}$ or Δt	0.10000	0.00347	0.00128

It will be noted from this table that the function $L=vt$ is a non-linear function.

In a similar manner Δt can be determined from the time diagram of Figure III as shown in Table II below where the same values for t have been taken. If the angle θ be taken as 90 degrees, then

$$\frac{L_1^2}{v^2}=\frac{L_0^2}{v^2}+\frac{d_1^2}{v^2}$$

Table II

t	0	1	2
v	5000	6000	7000
$\frac{L_0}{v}$	0	1	2
$\frac{d_1}{v}$	0.100	0.08333	0.07143
$\left(\frac{L_0}{v}\right)^2$	0	1	4
$\left(\frac{d_1}{v}\right)^2$	0.01000	0.00694	0.00510
$\left(\frac{L_0}{v}\right)^2+\left(\frac{d_1}{v}\right)^2$	0.01000	1.00694	4.00510
$\frac{L_1}{v}$	0.1000	1.003464	2.001275
$\Delta t=\frac{L_1}{v}-\frac{L_0}{v}$	0.10000	0.00347	0.00128

Accordingly, it follows that transforming the space diagram into a time diagram in the manner described provides a valid method of determining Δt the phase-time difference. From Table II it is seen that for the conditions specified, a trace recorded at a distance of 500 feet from the shot point with a reflection time 1 second would lag the trace recorded at the shot point by 0.00347 second. With a reflection time of 2 seconds, it would lag the trace recorded at the shot point by 0.00128 second. In other words, Δt becomes progressively but non-linearly smaller along the axis of the strip member as time after the instant of shot increases.

The mechanism of Figure IV is one embodiment of a mechanical apparatus for continuously computing the foregoing time differences, which when linked to a reproducing apparatus will continuously effect the necessary adjustments so as to bring each separate and individual trace into phase time coincidence with a reference trace corresponding to the output of a seismometer located substantially at the shot point.

As indicated in Figure IV, this apparatus consists of a vertical frame or arm **21** mounted above the scanner shown in Figure V which contains the movable pickups or slits. A second frame or arm **22** is suspended within the vertical frame and can be pivoted or rotated about the axis **23**. If desired, the frame **21** can be pivoted about this axis. Both frames may be referred to as director arms. Movable member **24** is made to slide along the frame **22** and is driven by a motor **30** through a suitable drive mechanism. Another movable element **31** is located within the vertical frame **21** and is driven through a suitable mechanism by a motor **35**. A linkage member or system of levers, advantageously in the form of a pantograph, connected at one end to the base element along the axis **23** and at the other end to the moving element **31** causes the point g to be moved in a line normal to the axis **23** as the element **31** is moved. A cable *abcdeghi* of constant length is connected from the top of the pickup **36** through a hole in the base point at b along *cde* of the pantograph links to the moving point g, thence through a hole h in the moving element **24** to a fixed point i at the far end of the frame **22**.

There are similar cables, one for each trace on the strip member, so connecting each of the pickup elements to the end of the frame **22**. Each of the cables passes through the moving element **24** which represents the image point in the space and time diagrams of Figures II and III, respectively. The terminus of the cable is at the fixed point i and is at a relatively great distance from the axis **23**, which axis represents the surface of the ground. The extent of movement of the member **24** from the axis **23** is governed by the length of the trace it is desired to reproduce.

The vertical distance gb will be different for each cable, however, since this distance gb corresponds to the

$$\frac{d}{v}$$

in Figure III. In the case of the shot point, this distance gb is 0, i. e., the shot point is located on the base element at the axis **23**. The point g is the effective detector position. The distance increases for each of the pickup points until a maximum distance is reached at the point representing the most remote detector from the shot point.

The reflecting horizon is, at any instant, midway between the shot point b and the image point element **24**.

A scale is provided so that a pointer **37** will indicate the angle of inclination of the movable frame **22**. The angle at which this frame rests changes the amount of movement obtained at the pickup for identical movements of the elements **24** and **31**.

The operation of the apparatus may be described briefly as follows: In starting out, the movable element **24** is as close to the axis **23** as possible. The member **31** is set at a height such as to cause the last trace pantograph to have its point g at a distance which is

$$\frac{d}{v_a}$$

for the most distant trace relative to the shot point, multiplied by a factor which takes into account the original speed of recording in the field and the optical magnification, if any, in the scanning mechanism. For example, if the recording speed is three inches of strip member per second and the optical magnification is 7×, then this factor would be 21.

The frame **22** is set at some predetermined angle relative to the vertical frame **21**, for example, 80° or 100° of inclination, this latter adjustment being for the purpose of correcting for the inclination of the reflecting horizon as will be discussed later.

The movable element **24** is started in its movement outward in the frame **22** by motor **30**. At the same instant motor **35** begins to drive the movable element **31** downward in the vertical frame **21**. The movement of element **24** corresponds to the time funtcion of the sound wave as it moves downward in the earth. The movement of the element **31** corresponds to the changes in the factor

$$\frac{d}{v}$$

as a function of time where v is the average velocity.

The speed of motors **35** and **30** is controlled to give the desired time relationships. The speed of the motor **30** is constant and provides the linear time function t. The motor **35** is indicated schematically as a servo mechanism, or the motor is coupled with a suitable linkage so that it is capable of injecting an inverse function of v.

The normal Δt of a record will be modified by the presence of dip in the reflecting beds, and in order to adjust for phase-time coincidence it will be necessary to adjust the angle of the director frame **22** with respect to frame **21**, making records at different angle settings, varying, for example, from +30° to −30° in 10 degree increments. Then the reproduced record is selected which most nearly aligns a particular record under study.

Correction of velocity function to take into account decreased absolute depth of the reflecting horizon in the presence of moderate or high angles of dip of the reflecting bed, can be accomplished in the case where it is assumed that $v=v_0+at$, by changing to the form $v=v_0+a \cos \alpha t$ where α is the assumed angle of the reflecting bed.

Thus, the motor **35** and its associate mechanism, when in operation, introduces into the mechanical analysis the non-linear

$$\frac{d_1}{v}$$

function which is indicated in the fourth line of Table II. The linear L_0/v function referred to in Table II is introduced by the lateral movement of the image point itself while the sliding ring effect of the moving element **24** upon the cables effects the subtraction of the last line of Table II.

The function

$$\frac{d_1}{v}$$

on the time diagram of Figure III shows that the point *g*, representing the detector, must move as velocity changes. In other words, the distance between points *g* and *b* varies inversely as the velocity.

Accordingly, the net effect of these movements of the two movable elements **24** and **31** is to lower the position of the slit or pickup since the cable *adcdeghi* is of constant length.

The portion *g*—*h* of any cable corresponds to a given reflection ray

$$\frac{L}{v_i}$$

at any instant while the portion *g*—*b* corresponds to

$$\frac{d}{v_i}$$

at any instant. The portion *b*—*h* corresponds to

$$\frac{L_0}{v_i}$$

which is the same as *t* (time).

As indicated in Figure IIIA, if all cables are of equal length t_T+k, then,

$$t_T+k=t_T-t_0+t_1+k-s_1$$

which upon simplification becomes:

$$s_1=t_1-t_0=\Delta t_1$$

Also,

$$t_T+k=t_T-t_0+t_n+k-s_n$$

which upon simplification becomes:

$$s_n=t_n-t_0=\Delta t_n$$

In Figure IIIA the vertical portions of the cable from *i* to *h* represent the corresponding portions of the cables on the director arm **22** of Figure IV extending from *i* to the sliding element **24**. The portion of cable #*n* (corresponding to any detector *n*) on the director arm from *h* to *g* (Figure IV) is equal to t_0 in Figure IIIA plus the value of Δt_n.

The value "*a*" in the term

$$\frac{a}{v}$$

as used in Figure IIIA, represents the distance between each of the equally spaced detectors **1**, **2** and **3**, the first of which is taken as some distance D from the shot point. Thus the detector #2 of Figure IIIA is a distance $d_2=(D+a)$ from the shot point. In this respect, therefore, the diagram of Figure IIIA is analogous to that of Figure III except that in Figure IIIA the angle θ has been taken as 90°.

As previously indicated there is a separate pantograph linkage for each cable and, therefore, for each trace. It is characteristic of a pantograph that the ratio of the distance from its fixed point (*b* in Figure IV) to any intermediate moving point *g* to the distance between its fixed point and the most remote moving point *f* is a constant. Therefore, linkages for the respective traces can be proportioned to correspond to the distance of each trace from the shot point.

In case of phonographic or magnetic strip members the pick-up points would operate directly on the strip member. But in the case of a photographic strip member, it is possible to operate either directly at the strip member or on a projected image thereof. It is generally advantageous to operate on an optically enlarged projection of the film so as to permit a greater degree of tolerance in mechanical construction. In such case, it will be necessary to adjust the degree of pick-up movement to conform to the time scale of the original strip member or to the equivalent time scale of the projected image which correction must be taken into account in designing the computing mechanism.

In order to correct for weathering, elevation and instrumental delay, provision, not shown, in the drawing, is made for adjusting the length of the cables. This is advantageously done by taking up or slacking off at the point *i*, or in the rod which operates the pick-up.

The purpose of passing the cable along the points *edc* as well as the points *g* and *b* of the pantograph linkage is to limit the extent of movement of the pick-up point so as to correspond to the actual movement of the cable through the eyelet at *g*. A possible alternative to passing the cable through these points of the pantograph linkage would be to (1) wind the cable on a spring-loaded drum at a point *g* to which the cable would be attached, or (2) pass the cable over a drum or pulley with tension maintained by a weight, and then transfer the drum or pulley motion by means of a flexible shaft, for example, coupled to the pick-up displacing means. Instead of this shaft an autosynchronous generator-motor system, sometimes called a repeater system, may be used.

It is not necessary that the reference point be taken at the shot point. It may be any other convenient point and might preferably be a point coincident with one of the seismometers whose output is recorded.

Translation of the reference point is achieved by subtracting Δt of the new reference point, as computed with the shot point as a reference, from the values of Δt for all other traces (also computed with the shot point as a reference).

This may be stated in equation form as follows:

$$\begin{aligned}\Delta_m t_n&=\Delta_0 t_n-\Delta_0 t_m\\ \Delta_0 t_n&=t_n-t_0\\ \Delta_0 t_m&=t_m-t_0\\ \Delta_m t_n&=(t_n-t_0)-(t_m-t_0)\\ &=t_n-t_0-t_m+t_0=t_n-t_m\end{aligned}$$

A suitable linkage can be incorporated in the mechanism to perform this operation. It may conveniently be located between points *b* and *a*.

The scanner **50** of Figure V through which the strip member **51** bearing the primary record travels lengthwise, is a device for performing the same general function as the scanner described in my co-pending application. In the present instance the slits **52A**, **52B**, **52C**, and **52D** for pick-up are mounted on rod members **36A**, **36B**, **36C** and **36D**, respectively. These rod members are slidably supported within the scanning box so that the slits are adjustable along the length of the traces such that their position may be adjusted to correspond to matching peaks on the several traces of the strip member **51**.

The upper end of each rod is connected to a cable as was indicated in Figure IV. Advantageously the scanner is mounted below the mechanism of Figure IV so that the rods are in a vertical position and thus can exert tension on their respective cables. If necessary, the rods can be spring-loaded so as to maintain sufficient tension on the cable, or to return the rods to their normal positions when the cables slack off as a result of operation of the moving elements in the director arms of the mechanism of Figure IV.

Numeral **55** designates a light source such that light passes through the juxtaposed film and slits. Advantageously, the film moves between the light source and the slits.

The individual light beams passing through the scanner go into a series of light proof boxes **99**, **100**, **101**, **102** provided respectively with photocells **103**, **104**, **105**, **106**. The individual photocells are in turn connected to the input of individual amplifiers **107**, **108**, **109**, **110**. These amplifiers may be tuned to pass any particular frequency or band of frequencies by adjustable filters (not shown) but incorporated in the respective amplifier circuits. The outputs of the amplifiers are supplied to a mixer. In the example illustrated by Figure V, one mixer circuit **111** may be employed to combine the output of the amplifiers **107**, **108**, and a second mixer circuit **112** may be employed to combine the output of amplifiers **109**, **110**. The outputs of the mixer circuits are fed to a recording camera-type multitrace galvanometer **113** through which a film **114** is passed in synchronization with the passage of the primary film **51** through the scanner. In this way a pair of traces **115**, **116** are produced on a secondary record or film **114**. The trace **115** is representative of the sum of the individual traces **56** and **57** on the primary record while the other trace **116** represents the addition of the primary traces **58**, **59**, compensation having been made for phase-time differences.

If desired, the gains of the individual amplifiers between photocells and mixer may be adjusted individually. For example, it may be desirable to add only half the amplitude of one of the original traces to the full amplitude of another.

In the operation of the apparatus the currents from the several seismometers or pick-ups represent the dynamite spectrum as picked up at the several field locations. These wide band compound waves are recorded on the primary film **51** and subsequently subjected to analysis. The analysis involves phase-time compensation employing the scanner, and it may also involve frequency discrimination through the tuning of the amplifier-filter combination. Analysis of the compound waves thus recorded on the primary record may be complete. Thus the primary record may be run through the re-recording apparatus any number of times with the amplifier-filter combinations of the re-recording apparatus tuned to any particular frequency or frequency band which is to be investigated. The most significant frequencies originally picked up may thus be isolated and investigated either individually or with any desired mixing schedule.

It may be desirable to reverse a given trace in the re-recording process. This can be accomplished in the apparatus of Figure V with the reversing switches **120**, **121**, **122**, **123** interposed in each case between the individual amplifiers and the mixer. Thus any wave may be reversed (so that its crest becomes its trough) prior to mixing. This may be done to correct for improper field connections, etc.

In lieu of the foregoing mechanical apparatus of Figure IV, the time corrections can be made with electrical circuits adapted to compute time differences, as more specifically illustrated in Figures VI to XI, inclusive. This electrical solution is based on the identity between the time diagram (Figure III) and a vector diagram in which voltage proportional to t_a in magnitude and having zero phase displacement (this being the reference phase) is combined with another voltage proportional to t_0 in magnitude and displaced in phase from t_a by an angle θ to obtain the resultant voltage proportional to t_n.

As is known any vector is fully identified in magnitude and positions with reference to the positive horizontal by writing it in the form A $(\cos\theta \pm j \sin\theta)$ where "j" is equal to $\sqrt{-1}$. Since the expression $(\cos\theta \pm j \sin\theta)$ is mathematically equivalent to $e^{\pm j\theta}$, it follows that the exponential expression of a vector is $Ae^{\pm j\theta}$ which is interpreted as a vector of absolute magnitude A, displaced from the horizontal axis of reference by an angle $\pm\theta$, the letter "e" being the base of natural logarithms and having the value 2.718 . . . , and θ being measured in radians.

Accordingly, the expression $t_a e^{j0}$ signifies that the vector t_a has a zero angle with respect to the positive X axis, while the expression $t_n e^{jB}$ signifies that the vector t_n is rotated from the positive X axis by an angle B. For present purposes, voltage is designated as time in the foregoing expressions.

Figure VI is a vector diagram showing the phase relationships between the various quantities involved in Figures VII and VIII. The absolute identity between this vector diagram and the transformed time diagram to be solved is apparent. Thus from this vector diagram it is seen that:

$$t_n e^{jB} = t_a e^{j0} + t_0 e^{j\theta}$$
$$t_n' e^{jB'} = t_a' e^{j0} + t_0 e^{j\theta}$$
$$t_n'' e^{jB''} = t_a'' e^{j0} + t_0 e^{j\theta}$$
$$t_n''' e^{jB'''} = t_a''' e^{j0} + t_0 e^{j\theta}$$

In order to obtain the scalar value of the difference between the absolute values of t_n and t_0, it is necessary to convert $t_0 e^{+j\theta}$ and $t_n e^{+jB}$ into scalar values. This can be done by use of a peak voltmeter which rectifies the alternating current and produces a D. C. voltage proportional to the peak value of the vector quantity. These scalar values may then be subtracted to obtain a voltage proportional to Δt_n. This voltage may be fed into a D. C. amplifier which operates a solenoid to displace slit "n" by an amount proportional to Δt_n.

In Figure VII, section (a) comprises a 3-phase alternating current transformer **200** having three fixed windings and one rotatable winding. The letters A, B, and C, designate input leads. The characteristic of the transformer is such that the output voltage is constant and the phase of the output voltage is continuously variable throughout 360°.

Section (b) of Figure VII comprises an autotransformer **201**, the input terminals of which are connected with the variable phase winding of transformer **200**, thus having a constant voltage of adjustable phase impressed upon it, and having a slideable contact arm **202** permitting the magnitude of the output voltage ($t_0 e^{j\theta}$) to be adjusted continuously from zero to a maximum value, depending upon the magnitude of the input voltage.

Section (c) of Figure VII is identical to section (b) having an autotransformer **203**, except that the input voltage is taken from the supply lines AB. The phase of the voltage AB is taken as the reference phase ($t_a e^{j0}$) which is equivalent to t_a, the reference phase having zero phase displacement. The numeral **204** designates a slideable contact arm.

Section (d) of Figure VII comprises a peak reading volt-meter **205** producing a unidirectional voltage (D. C.) whose magnitude is proportional to the absolute quantity t_0.

Section (e) of Figure VII comprises a peak reading volt-meter **206** identical to that of section (d) which produces a unidirectional voltage (D. C.) whose magnitude is proportional to the vector sum of t_0 and t_a, meaning that they are added in their proper phase relation. The letters M and N designate output leads.

In operation of the circuit of Figure VII the voltage output from section (d) is proportional only to the magnitude of t_0 and the output from section (e) is proportional to the magnitude of the vector sum of $t_0 + t_a$. By placing the outputs of these two sections (d) and (e) in series opposing, a voltage equivalent to the difference between the output t_n of section (e) and the output t_0 of section (d) is obtained. This voltage difference is a measure of Δt_n.

Given a direct voltage proportional to the quantity Δt_n, this voltage may be applied to the input of an element capable of producing a mechanical displacement proportional to the input quantity Δt_n. This element may take the form of a direct current amplifier **210** and a solenoid **211** whose plunger is mechanically linked to a pick-up rod **36**, as indicated in Figure VII. This element may include auxiliary means for placing a voltage proportional to weathering, elevation, and instrumental delay corrections, in series with the voltage proportional to Δt_n so that the ultimate displacement of the pick-up will be proportional to the algebraic sum of these voltages.

In section (*b*) of Figure VII the slider **202** represents the image point *h* of Figure III. A motor (not shown) moves the slider at a uniform rate starting at the bottom, when $t=0$, so that the output of the auto transformer is zero and uniformly increases the voltage during the process of reproducing the record. This voltage is the function t_0 itself and the phase relation of t_0 to the reference phase is equivalent to 90° ± the angle α where α is the slope angle for which the record is being examined.

In section (*c*) of Figure VII the slider **204** represents the effective detector point *g* of Figure IV. At the time $t=0$, the magnitude of t_a is proportional to the quantity

$$\frac{d}{v_0}$$

which is the distance of the detector from the shot point divided by the initial velocity. The quantity t_a varies so that the proportionality of t_a to

$$\frac{d}{v_i}$$

(v_i equals instantaneous velocity) is maintained, that is t_a varies inversely as v. A motor and inverser linkage (not shown) operates the slider **204**, moving it downwardly. If it is desirable in the presence of moderate or steep depths to correct the velocity function for the decreased depth of the reflecting point, such correction may be made by reducing the rate at which t_a is decreased so that the resultant velocity function would take the form, for example, $v=v_0+\alpha \cos \alpha t$, where α=dip angle.

Figure VIII illustrates the manner in which the quantities t_n, t_n', t_n'' are obtainable. This figure comprises multiple peak reading voltmeters to be employed in place of the single unit of section (*e*) of Figure VII. Between the point D on the slider **204** and the point B, being the bottom of the auto transformer **203**, there is a tapped voltage dividing resistor **207**. The letters D′, D″, and D‴ designate intermediate taps on this resistor. The voltages t_n', t_n'', and t_n''' are measured from a common terminal P to a terminal designated respectively M, M′, M″ and M‴. Thus with the shot point as a reference:

$$\Delta t_n = t_n - t_0$$
$$\Delta t_n' = t_n' - t_0$$
$$\Delta t_n'' = t_n'' - t_0$$
$$\Delta t_n''' = t_n''' - t_0$$

As previously indicated the upward motion of the slider **202** along the winding of auto transformer **201** injects the independent variable t_0 and this action is thus equivalent to the outward movement of the sliding element **24** of Figure IV. The proportional voltage divider **207** connected between points D and B of Figure VII injects the inverse velocity function thus performing the function of the pantograph linkages of Figure IV. Thus regardless of how many traces are to be corrected, there need be only the two auto-transformers, the first of which increases its output linearly with time, and the second of which decreases its output according to the inverse velocity function.

Figure IX illustrates how the multiple trace computing system of Figure VIII is hooked up to the amplifiers and "pickup" actuating solenoids. The block **212** designates the time difference computing circuit of Figure VIII with its output terminals M, M′, M″, M‴, and also the output terminal or lead N (shown in Figure VII). As shown, there are provided direct current amplifiers **210**, **210′**, **210″**, **210‴**, respectively, for each of the output terminals of the time difference computing circuit. The output from each amplifier is fed to its respective solenoid, **211**, **211′**, etc. The numeral **213** designates a multi-position switch. In the position as drawn, the switch connects the common terminal of all the amplifiers to the terminal N of the time difference computing circuit thereby using the shot point as the reference trace to which all corrections are computed. If the arm of the selector switch is moved one step clockwise, the input leads of the amplifier **210‴** are shorted. Under this condition, only such auxiliary corrections as might be set up within that amplifier for weathering, elevation, instrumental delay, etc., would appear in the output terminals from this amplifier to actuate its solenoid. If trace M‴ is to be used as the reference trace, it, of course, should suffer no other corrections.

The circuits are such that the voltage applied to the input of a particular amplifier is its own t_n minus the t_n of the reference trace. Therefore, the input voltage is proportional to the difference between the t_n of the particular amplifier and the t_n of the reference trace, which is the condition desired. Any trace at all may be used as a reference trace. However, if the most distant trace from the shot point is used, a negative correction may be required from the direct current amplifier.

In order to provide a sensing characteristic to the solenoids, solenoid polarizing coils **214**, **214′**, etc., may be employed and which would operate from a source of polarizing direct current.

Although a system having 4 traces has been illustrated, it is contemplated that the system might involve any number of traces, for example, 12 traces, 24 traces, or whatever number desired.

The electrical computer system has some advantages over the mechanical computer previously described. With the mechanical computer, it is necessary that the first trace of the primary strip record be connected to a detector which is subtsantially at the shot point with distance from the shot point increasing successively for each successive trace. In field practice, it is generally convenient to shoot first on one end of the spread and then, without disturbing the instrument setup, shoot on the opposite end. This is not possible unless some change is made either in the spread or in the connections to the amplifiers within the instrument truck.

Furthermore, it may be desired to locate the shot point some distance away from the first detector, in which case the pantographs of the mechanical computer would have to be changed and the entire system restrung before operations could be resumed on the equipment.

By a simple modification of the electrical computing circuit it is possible to take care of any desired position of the shot point whether it be at either end, at any place between any two traces, or at any distance from either end of the instrument setup.

Figure X illustrates the arrangement wherein the shot point corresponds to a point located midway between points D″ and D‴. As indicated, the connection between the slider **202** and the input lead B of auto-transformer **203** is removed. Instead, slider **202** is connected to a movable contact point **220** on the proportional voltage dividing resistor **207**. The peak voltmeter for determining t_0 still connects to the slider **202** so that only the voltage between the slider **202** and the terminal P is measured. A section of resistance **207‴** may be provided between D‴ and the input lead B. Also there may be a section of resistance (not shown) between point D and the slider **204**. Each of these two end resistance sections may be of appropriate value so as to allow movement of the shot point as far as desired outside of the limits of the instrument spread itself.

If desired, a large number of taps may be provided on the resistor in place of a sliding contact, since the shot point should seldom be placed other than at the point midway between detectors.

Figure XI comprises a vector diagram for the case where the shot point is midway between D″ and D‴. Since the diagram is patterned after that illustrated in Figure VI, no additional explanation appears necessary.

An advantageous feature of the invention is that one may scan the record being reproduced for variable slope angles during the process of reproduction. For example, it is frequently found that slope angles of reflecting beds tend to increase with depth. Thus a record might contain 3° dips at reflection arrival times of one-half second and contain dips of 15 to 20° for reflection arrival times of three seconds. If the dips of the reflections vary according to any reasonably regular scheme, the phase angle θ may be varied as a function of time so as to conform to that scheme.

Mention has been made of detectors **1**, **2**, **3**, and *n*, etc., by which it is understood that there may be any number of detectors. In certain of the appended claims reference will be made to detectors *n* and *r*, for example, arbitrarily selected from a string of detectors extending from the shot point.

Obviously, many modifications and variations of the invention, as hereinbefore set forth, may be made without departing from the spirit and scope thereof and, therefore, only such limitations should be imposed as are indicated in the appended claims.

I claim:

1. In vibration wave analysis of a plurality of traces on a strip member in reproducible form, said traces being made by the responses of receptors at a plurality of points differently located relative to a common source of disturbance such that there is a phase-time difference between the separate traces, apparatus for continuously determining the amount of time correction required to bring each separate and individual trace into phase-time coincidence with a reference trace corresponding to the output of a receptor located at a selected reference point, which comprises means for producing a voltage output proportional to the time required for a reflected sound wave to reach the receptor at the reference point, means for producing a separate voltage output proportional to the time required for a reflected sound wave to reach a receptor spaced from the reference point, and means placing said voltage outputs in series opposing, thereby obtaining a resultant voltage output indicative of the magnitude of said time correction.

2. In vibration wave analysis of a plurality of traces on a strip member in reproducible form, said traces being made by the responses of receptors at a plurality of points differently located relative to a common source of disturbance such that there is a phase-time difference between the separate traces, apparatus for continuously dedetermining the amount of time correction required to bring each separate and individual trace into phase-time coincidence with a reference trace corresponding to the output of a receptor located at a selected reference point, which comprises means for producing a voltage output proportional to the time required for a reflected sound wave to reach the receptor at the reference point, means for producing a separate voltage output proportional to the time required for a reflected sound wave to reach a receptor spaced from the reference point, means for converting each of said voltage outputs to unidirectional voltage outputs, and means for algebraically combining the converted voltage outputs thereby obtaining a resultant voltage output indicative of the magnitude of the time correction.

3. In vibration wave analysis of a plurality of traces on a strip member in reproducible form, said traces being made by the responses of receptors at a plurality of points differently located relative to a common source of disturbance such that there is a phase-time difference between the separate traces and wherein all dimensions of a wave travel space diagram when divided by wave velocity, expressed as a function of time, results in a vector diagram in which the magnitude of the first vector is proportional to t_0, the time required for a reflected sound wave to reach a receptor substantially at the point of disturbance, the magnitude of the second vector is proportional to t_a, which is the distance between the disturbance point and another receptor divided by the instantaneous value of average velocity, and the magnitude of the third vector is proportional to the vector sum of the first and second vectors, apparatus for continuously determining the amount of time correction required to bring each separate and individual trace into phase-time coincidence, with the output of the receptor at the disturbance point, which comprises means for producing a voltage output proportional to the magnitude of t_0, means for producing a separate voltage output proportional to the magnitude of the vector sum t_0+t_a, and means for placing said voltage outputs in series opposing, thereby obtaining a resultant voltage output indicative of the magnitude of said time correction.

4. In vibration wave analysis of a plurality of traces on a strip member in reproducible form, said traces being made by the responses of receptors at a plurality of points differently located relative to a common source of disturbance such that there is a phase-time difference between the separate traces and wherein all dimensions of a wave travel space diagram when divided by wave velocity, expressed as a function of time, result in a vector diagram "*x*" in which the magnitude of the first vector is proportional to t_0, the required time for a reflected sound wave to reach a receptor substantially at the point of disturbance, the magnitude of the second vector is proportional to t_{an} which is the distance between the disturbance point and a second receptor "*n*" divided by the instantaneous value of average velocity, and the magnitude of the third vector is proportional to the sum of the first and second vectors; and also results in another vector diagram "*y*" in which the magnitude of the first vector is proportional to t_0, the magnitude of the second vector of diagram "*y*" is proportional to t_{ar} which is the distance between the disturbance point and a third receptor "*r*" divided by the instantaneous value of average velocity and the magnitude of the third vector of diagram "*y*" is proportional to the vector sum of the first and second vectors of diagram "*y*," apparatus for continuously determining the amount of time correction required to bring each separate and individual trace into phase-time coincidence with the output of the receptor "*r*" which comprises means for producing a voltage output proportional to the magnitude of the vector sum t_0+t_{an}, means for producing a second voltage output proportional to the magnitude of the vector sum t_0+t_{ar}, means for converting each of said voltage outputs to unidirectional voltage outputs, and means for algebraically combining the converted voltage outputs thereby obtaining a resultant voltage proportional to the difference between the two converted voltages indicative of the magnitude of the time correction.

5. In vibration wave analysis of a plurality of traces on a strip member in reproducible form, said traces being made by the responses of receptors at a plurality of points differently located relative to a common source of disturbance such that there is a phase-time difference between the separate traces, apparatus for continuously determining the amount of time correction required to bring each separate and individual trace into phase-time coincidence with a reference trace corresponding to the output of a receptor located at a selected reference point, which comprises means for producing a first alternating voltage of proper phase and controllable magnitude proportional to the time required for a reflected sound wave

to reach the receptor at the reference point, means for producing a second alternating voltage of proper phase and controllable magnitude proportional to the reciprocal of the instantaneous value of average velocity, where velocity is expressible as a function of time, a tapped proportional voltage divider, means for applying said second alternating voltage to said tapped proportional voltage divider one terminal of which is connected to a first terminal of said first alternating voltage producing means and the individual taps of which are representative of the positions of the separate receptors, means for producing a unidirectional voltage whose magnitude is proportional to the first alternating voltage, means for producing individual unidirectional voltages proportional respectively to the vector sums of the first alternating voltage and that fraction of the second alternating voltage existing between the aforementioned first terminal and each separate tap of the aforesaid voltage divider, and means for separately combining algebraically the aforesaid unidirectional voltage whose magnitude is proportional to the first alternating voltage with each aforesaid individual unidirectional voltage thereby obtaining individual resultant voltages representative of the magnitude of the respective phase-time differences of the separate receptors with respect to the selected reference point.

6. A vibration wave analyzer for a plurality of traces on a strip member in reproducible form, said traces being made by the responses of receptors at a plurality of points differently located relative to a common source of disturbance such that there is a phase-time difference between the separate traces, comprising a scanner containing a pickup element for each trace on the strip member and responsive to variations in said trace, electrical circuits for determining the amount of time correction required to bring each separate and individual trace into phase-time coincidence with a reference trace corresponding to the output of a receptor located at a selected point with reference to the point of disturbance, means for displacing each individual pickup along the time axis of the strip member by said amount and means for reproducing the record with the displaced pickups.

7. A vibration wave analyzer according to claim 6 wherein the electrical circuits for determining a phase-time difference comprise means for maintaining a voltage output proportional to the magnitude of t_n, the time required for a reflected sound wave to reach any receptor "n," means for maintaining a voltage output proportional to the magnitude of t_r, the time required for a reflected sound wave to reach a reference receptor "r" and means for placing said voltage outputs in series opposing, including means for obtaining a resultant voltage indicative of the magnitude of said difference.

8. A vibration wave analyzer according to claim 6 wherein the electrical circuits for determining a phase-time difference comprise means for maintaining a voltage output proportional to the magnitude of t_n, the time required for a reflected sound wave to reach any receptor "n," means for maintaining a voltage output proportional to the magnitude of t_r, the time required for a reflected sound wave to reach a reference receptor "r," means for placing said voltage outputs in series opposing, including means for obtaining a resultant voltage indicative of the magnitude of said difference, and means utilizing said resultant voltage for actuating an individual pickup displacing means.

9. A vibration wave analyzer according to claim 6 wherein the electrical circuits for determining a phase-time difference comprise means for maintaining a voltage output proportional to the magnitude of t_n, the time required for a reflected sound wave to reach any receptor "n," means for maintaining a voltage output proportional to the magnitude of t_r, the time required for a reflected sound wave to reach a reference receptor "r," means for placing said voltage outputs in series opposing, including means for obtaining a resultant voltage indicative of the magnitude of said difference, amplifying means for amplifying an individual resultant voltage and a solenoid responsive to the output from said amplifying means and adapted to displace an individual pickup.

10. A vibration wave analyzer according to claim 6 wherein the electrical circuits for determining phase-time differences comprise means for maintaining a voltage output proportional to the time required for a reflected sound wave to reach a receptor located at a selected reference point, means for maintaining separate and individual voltage outputs each proportional to the time required for a reflected sound wave to reach other individual receptors spaced from the reference receptor and means for separately combining algebraically the first mentioned voltage with each of said other separate and individual outputs thereby obtaining individual resultant voltages representative of the magnitude of the respective phase-time differences of the separate receptors with respect to the selected reference receptor.

11. A vibration wave analyzer according to claim 6 wherein the electrical circuits for determining phase-time differences comprise means for maintaining a voltage output proportional to the time required for a reflected sound wave to reach a receptor located at a selected reference point, means for maintaining separate and individual voltage outputs each proportional to the time required for a reflected sound wave to reach other individual receptors spaced from the reference receptor, means for separately combining algebraically the first mentioned voltage with each of said other separate and individual voltage outputs thereby obtaining individual resultant voltages representative of the magnitude of the respective phase-time differences of the separate receptors with respect to the selected reference receptor and means utilizing each resultant voltage for actuating its respective pickup displacing means.

12. A vibration wave analyzer according to claim 6 wherein the electrical circuits for determining phase-time differences comprise means for producing a first alternating voltage of proper phase and controllable magnitude proportional to the travel time from the instantaneous image point position to a receptor substantially at the surface of the earth directly above the source of disturbance; a tapped proportional voltage divider; means for producing a second alternating voltage of proper phase and controllable magnitude proportional to the reciprocal of the instantaneous value of velocity, where velocity is expressible as a function of time, and for applying said second alternating voltage to said tapped proportional voltage divider; contact means slidably cooperating with said proportional voltage divider connecting a first terminal of the first alternating voltage source to a selected point representative of the position of the point of disturbance with respect to the position of the several receptors; means for producing a unidirectional voltage whose magnitude is proportional to the first alternating voltage; individual means for producing unidirectional voltages proportional respectively to the vector sums of the first alternating voltage and that fraction of the second alternating voltage existing between the aforementioned slidable contact, representative of the point of disturbance, and each separate tap of the aforementioned tapped voltage divider, representative of the positions of the separate receptors; a common terminal with respect to which all the aforementioned unidirectional voltages are measurable from each of the other separate unidirectional voltage terminals and to which is also connected the second terminal of the first alternating voltage source; means for selecting any one of the above-mentioned terminals except the common terminal as a reference point, thereby obtaining unidirectional voltages between each of the other terminals and the reference terminal representative of the magnitude of the respective phase-time differences of the separate receptors with respect to the selected reference point.

13. A vibration wave analyzer for a plurality of traces

on a strip member in reproducible form, said traces being made by the responses of receptors at a plurality of points differently located relative to a common source of disturbance such that there is a phase-time difference between the separate traces, comprising a scanner containing a pickup element for each trace on the strip member and responsive to variations in said trace, means for continuously producing a voltage having a magnitude proportional to the amount of time correction required to bring each separate and individual trace into phase-time coincidence with a reference trace corresponding to the output of a receptor located at a selected point with reference to the point of disturbance, means operatively connected to the aforesaid voltage producing means for continuously displacing each individual pickup along the time axis of the strip member by said amount and means for reproducing the record with the displaced pickups.

14. A vibration wave analyzer for a plurality of traces on a strip member in reproducible form, said traces being made by the responses of receptors at a plurality of points differently located relative to a common source of disturbance such that there is a phase-time difference between the separate traces, comprising a scanner containing a pickup element for each trace on the strip member and responsive to variations in said trace, means for continuously producing a voltage having a magnitude proportional to the amount of time correction required to bring each separate and individual trace into phase-time coincidence with a reference trace corresponding to the output of a receptor located at a selected point with reference to the point of disturbance, means responsive to said voltage for displacing each individual pickup along the time axis of the strip member by said amount and means for reproducing the record with the displaced pickups.

15. In vibration wave analysis of a plurality of traces, apparatus for continuously determining the amount of time correction required to bring each separate and individual trace into phase-time coincidence with the output of a receptor disposed substantially at a disturbance point, said apparatus comprising means for producing a first voltage proportional to the magnitude of t_0, the time required for a reflected sound wave to reach the receptor disposed at the disturbance point, means for producing a second voltage proportional to the magnitude of t_a, where t_a is the distance between the disturbance point and another receptor divided by the instantaneous value of average velocity, means for combining said first and second voltages vectorially so as to produce a resultant voltage proportional to the time required for a reflected sound wave to reach said other receptor and means for combining said first voltage and said resultant voltage to produce a scalar difference indicative of the magnitude of said time correction.

16. In vibration wave analysis of a plurality of traces on a strip member in reproducible form, said traces being made by the responses of receptors at a plurality of points differently located relative to a common source of disturbance such that there is a phase-time difference between the separate traces, apparatus for continuously determining the amount of time correction required to bring the separate and individual traces into phase-time coincidence with one another, which comprises means for producing a voltage having a magnitude proportional to the time required for a reflected sound wave to reach a reference point, means for producing a voltage having a magnitude proportional to the time required for a reflected sound wave to reach a receptor spaced from said reference point and means for combining said voltages to produce a scalar difference indicative of the magnitude of said time correction.

References Cited in the file of this patent

UNITED STATES PATENTS

2,087,702	Peters	July 30, 1937
2,166,991	Guanella	July 25, 1939
2,286,567	Parr	June 16, 1942
2,348,409	Parr	May 9, 1944
2,348,411	Petty	May 9, 1944
2,401,779	Swartzel	June 11, 1946
2,463,534	Hawkins	Mar. 8, 1949
2,581,456	Swift	Jan. 8, 1952
2,732,025	Lee	Jan. 24, 1956