

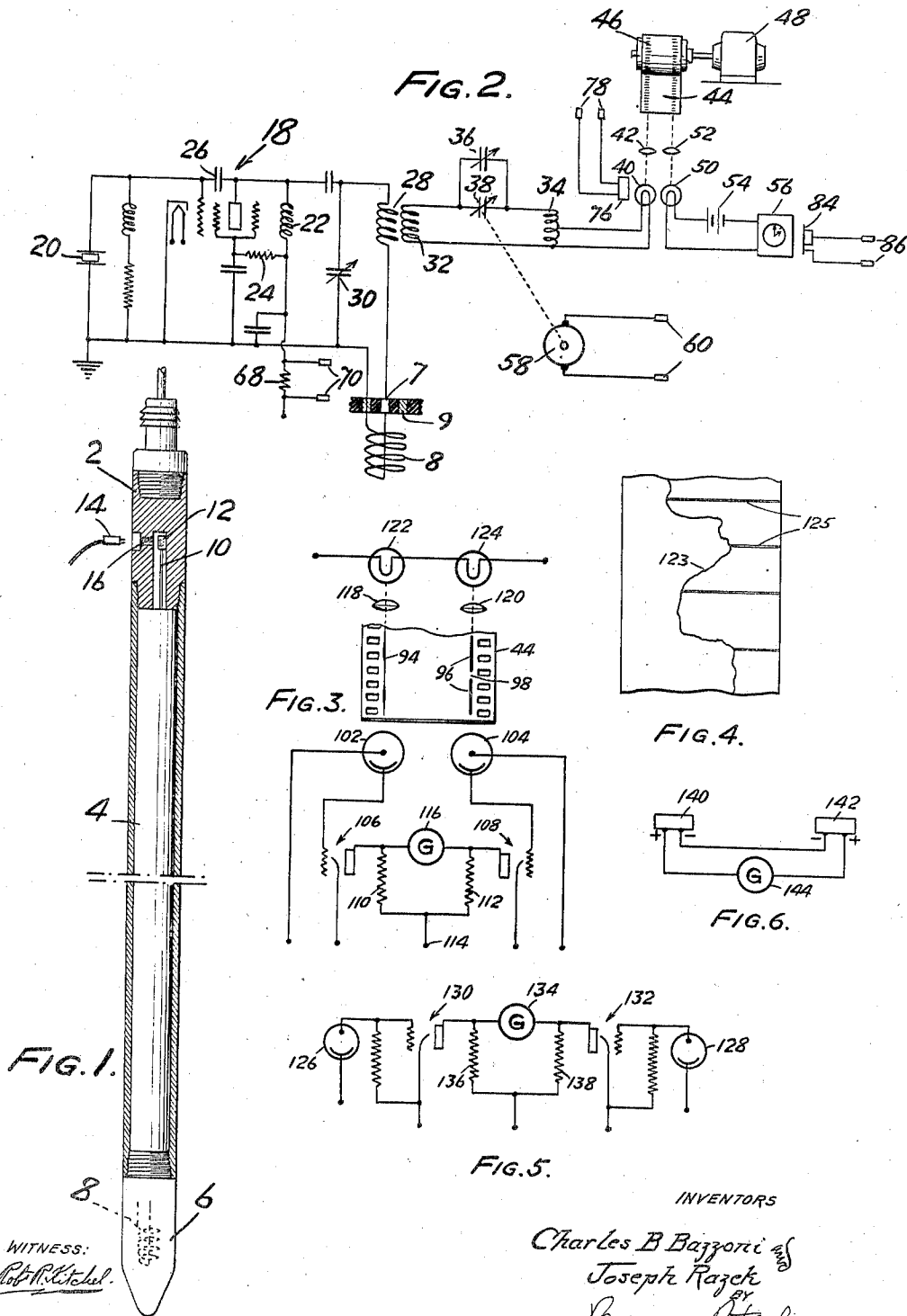
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ELECTRICAL PROSPECTING METHOD AND APPARATUS

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ELECTRICAL PROSPECTING METHOD AND APPARATUS

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This invention relates to the art of geophysical prospecting and, more particularly, by so-called electrical coring, to the determination of the nature and boundaries of formations traversed by bore holes.

In our applications Serial Nos. 72,246, filed April 2, 1936, and 222,609, filed August 2, 1938, there are described methods and apparatus for electrical prospecting, the methods involving lowering into bore holes suitable apparatus arranged to propagate high frequency oscillations into the strata surrounding the apparatus. By causing the oscillation producing apparatus to be affected by the strata in its vicinity, a measurement of the electrical conditions of the apparatus will give an indication of the formations which are encountered.

More specifically, as disclosed in the above mentioned application, Serial No. 222,609, there is produced a record of photographic type including two traces, one of which involves a variable density dependent upon the different electrical properties of the formations encountered, while the other involves a generally uniform density except for breaks which give timing indications. The type of record thus obtained may be scanned by photoelectric means to translate the variable density record of variations of properties of the strata into a corresponding curve on another record member, which may be better used for interpretative purposes.

In a device of the character indicated, it is difficult to maintain the film travelling at an even speed without mechanical complications. This is particularly true in a self-contained apparatus in which the drive must be of direct current type rather than a carefully governed type such as may be secured by the use of alternating current of practically constant frequency. If the film momentarily slows down, the corresponding portion of the recording track will have an increased density, and vice versa, and such density changes would be translated in a simple scanning apparatus as variations in the properties of strata.

In accordance with the present invention, the prospecting method includes the simultaneous scanning of both the recording trace and timing trace and the two are balanced against each other to eliminate or minimize the effects of nonuniform film movement. That this may be done may be understood by considering that if the film momentarily slows down an increased exposure will result in both the traces to corresponding degrees and by suitable provision of

scanning means the effect of the slowing down may thus be cancelled out.

The present invention however, is not necessarily limited to electrical prospecting by means of high frequency, since records obtained by the use of electrodes responding to direct currents or low frequency currents may also be in the form of variable density traces which may require correction for nonuniformity of film movement. The more general application of the invention will be clear from the following description.

Briefly stated, the object of the present invention is the provision and analysis of records involving variable density traces in such fashion as to secure valid translation of such traces into readily interpretable records.

The above object, and other objects of the invention particularly relating to details, will be apparent from the following description, read in conjunction with the accompanying drawing in which:

Figure 1 is a sectional view showing the protective casing of a high frequency type of exploring apparatus, the field producing means thereof, the interior apparatus, and monitoring and adjusting means;

Figure 2 is a diagram showing the wiring of the apparatus, and also the recording devices thereof;

Figure 3 is a wiring diagram of a preferred form of scanning apparatus for translating a variable density record into a record of readable type;

Figure 4 is a fragmentary portion of the type of record produced by the use of the scanning device;

Figure 5 is a wiring diagram of an alternative form of scanning device; and

Figure 6 is the wiring diagram of still another form of scanning device.

Referring first to Figures 1 and 2, there is illustrated therein a preferred type of prospecting apparatus of high frequency type, as disclosed more fully in our application Serial No. 222,608. This apparatus comprises a protective casing made to withstand the enormous pressures encountered in deep holes. This casing contains interior apparatus indicated generally at 4 and comprising an oscillator, recording mechanism and electrical power supplies therefor. At the lower end of the protective casing, there is located a nose of nonconductive material such as Bakelite, in which there is embedded a coil which provides for the propagation of a high

frequency field in the surrounding strata. Instead of a coil such as 8, it will be obvious that a suitable antenna arrangement may be employed as discussed in our earlier application, Serial No. 72,246. The leads from the coil or antenna preferably pass, respectively, to a central plug 7 and an annular ring 9 mounted in an insulating plug in the lower portion of the protective casing, as indicated diagrammatically in Figure 2. By the use of this concentric arrangement, there is avoided a considerable inductance such as would result if the leads passed through openings in an iron casing.

In the upper portion of the protective casing, connected by a cable 10 to the apparatus within the casing, there is a socket member 12 having a number of sockets adapted to be engaged by the prongs of a plug indicated at 14 which, when the apparatus is being adjusted may be inserted through a tapped opening 16, which is later to be closed by a fluid-tight plug when the apparatus is lowered in a hole.

The oscillator constituting the field producing means of the apparatus comprises a tube 18, preferably of the pentode, or equivalent, type. The oscillating circuit of this tube is substantially conventional, the frequency being determined by means of a crystal 20. Plate current is supplied through a choke 22 and screen current through a voltage drop resistor 24. A small condenser 26 between the grid and plate of the tube may be provided to secure the feed back necessary for oscillation. The tank circuit of the oscillator includes in series the coil 8 and the second coil 28 in parallel with a condenser 30, which is desirably variable for initial adjustment. Coupled to the coil 28 there is a wave meter circuit comprising two coils 32 and 34 and a pair of condensers 36 and 38, arranged in parallel. The former of these is the main adjusting condenser, while the latter is a trimmer condenser adapted to be adjusted as indicated hereafter. Coupled to the wave meter circuit is a recording lamp 40, which is arranged to project a spot of light through an optical system indicated at 42 upon a continuously slowly moving film 44 arranged to be wound upon a reel 46 by means of a motor and gear reduction arrangement indicated at 48.

A second lamp 50 is provided for timing purposes, and also for the purpose of balancing out the effects of variations in film speed as described hereafter. This lamp 50 is adapted to project upon the film 44 a spot of light through an optical system indicated at 52. The lamp 50 is energized by a battery 54, the circuit being controlled by a clockwork switch arrangement indicated at 56, which is adapted to interrupt the current through the lamp 50 periodically so as to give timing marks as hereafter described.

In the operation of the apparatus all the parts are set in adjustment as indicated hereafter, and the apparatus is lowered down the hole. Under these circumstances, the illumination of the lamp 50 varies as different strata are encountered in the vicinity of the coil 8, with the resultant production of a record of varying density on the film, as indicated at 94. Simultaneously a timing record is produced as indicated at 96, this timing record preferably having short interruptions made at definite intervals, as indicated at 98, with periodic longer interruptions, say at every tenth interruption, in order to facilitate counting. By correlating the making of the timing marks with a watch at the surface before the instrument is

lowered and noting the depths reached at different times, it will be obvious that the records provided by the variable density track 94 may be readily correlated with the depths at which they are produced.

The adjustment of the apparatus, which is highly sensitive, is difficult and is carried out, as more fully described in our copending application Serial No. 222,609.

The primary adjustment necessary after the apparatus is placed under conditions simulating those in the bore hole after assembly is complete is that of the trimming condenser 38, which is accordingly coupled by means of a shaft to a motor and reduction gearing assembly indicated at 58. The motor leads are connected to the sockets 60 in the socket member 12. These may be engaged by corresponding prongs of the plug 14, connected with a supply of driving current. Various indicators are used to determine whether the circuit is properly operating. By providing a small resistance 68 in the plate power lead and connecting the ends of this resistance to sockets 70, the oscillating condition may be determined by noting the readings of a milliammeter plugged into said sockets. Determination of illumination of the lamp 40 is obtained by providing a photoelectric cell 76, which is connected to socket members 78. Operation of the timing apparatus may be ascertained by locating adjacent to it a microphone 84 connected to sockets 86 in the socket member 12. The plug 14 is provided with suitable prongs connected to exterior apparatus as described in our copending application.

The present invention relates primarily to the type of record trace produced and the apparatus for translating the same into a readable record from which interpretations of the results may be made. The timing trace is not only useful for indicating a scale of time along the recording trace, but has the additional function of permitting a check to be made as to whether the variable density of the recording trace may be partially or wholly due to variations in speed of feed of the film. As indicated above, it is rather difficult to secure a uniform speed of movement of the film, and the necessity for uniform speed may be obviated if in analyzing the record comparative measurements are made of the density of the record trace.

For this purpose there is preferably used the analyzing apparatus of the type illustrated in Figure 3. This comprises two photoelectric cells 102 and 104 of either the vacuum or gas-filled type, though preferably of the vacuum type if a high degree of accuracy is desired. These cells should have substantially identical characteristics, the same being true of the two vacuum tubes 106 and 108, to the grids of which they are directly connected as indicated in Figure 3. The plates of the tubes 106 and 108 are connected to the plate voltage supply terminal 114 through high resistances 110 and 112 of equal value. Between the two plates there is connected a recording galvanometer 116, preferably of highly sensitive type and having either built into it or in series with it a high resistance substantially higher than the values of the resistances 110 and 112. While in practice this may take the simpler form of a recording galvanometer, it would be theoretically preferable to use a recording potentiometer, though this is not necessary considering the fact that what is primarily desired is a

qualitative indication of the characteristics of the strata.

The circuit so far described is of special type and need not be described in greater detail, since each half of it comprises a known type of circuit described by John Russell in the "Review of Scientific Instruments," December, 1937, under the title "A Photoelectric Cell Circuit with a Logarithmic Response." A brief outline of this article will be found in "Electronics" of February, 1938, page 62. The circuit described involves two logarithmic phototube circuits of the type described in said articles so located that the galvanometer 116 is affected differentially by them. For the purpose of the present description it need only be pointed out that the plate current of each of the tubes varies as the logarithm of the light intensity incident upon the sensitive surface of its corresponding photocell. In conjunction with the two photocells 102 and 104 there are arranged light sources 122 and 124, which, through optical means conventionalized at 118 and 120, project light beams through the recording and timing traces, respectively, upon the sensitive surfaces in the photocells. This is shown in conventionalized fashion, since the slits, lamp filaments, lenses, etc. are arranged in the usual fashions common in the sound picture art. The two lamps 122 and 124 are preferably illuminated from the same source and the optical systems are made identical so as to secure comparable results in the two tubes, though as will be obvious from the analysis of the operation below, due account may be readily taken of variations in the optical systems, etc. It is, however, desirable that a single source or accurately corresponding sources of light be used, so that if variations occur they are the same in the rays reaching the two traces.

With the arrangement indicated, the film 44 is moved slowly through the scanning apparatus whereupon the galvanometer 116 makes a record of the type illustrated in Figure 4. The fashion in which variations in the original film velocity are balanced out will be obvious from consideration of the following, wherein it will be seen that the logarithmic responses of the two photocell circuits result in complete elimination of the variations in film speed:

The exposure given to a point on a dash of the timing trace is

$$I \cdot \frac{1}{v}$$

in which I is proportional to the intensity of the source and v is the film speed when the point is exposed. The exposure of the corresponding point on the recording trace is

$$kI \cdot \frac{1}{v} \cdot f$$

in which f represents the effect of the traversed strata which is being secured as a function of time, later to be transformed into a function of depth, and k is a factor of proportionality for the intensities.

On the straight portion of the H & D curve for the film used, the density of each record is proportional to the logarithm of the exposure. But the density of the record being the negative logarithm of the transmission, we have, if γ is the contrast to which the film is developed, F_t is the light transmission of the timing trace, and F_r the

light transmission of the corresponding portion of the recording trace:

$$-\log F_t = \gamma (\log I - \log v)$$

$$-\log F_r = \gamma (\log I - \log v + \log f)$$

But due to the circuit arrangement, the galvanometer current

$$i_g = c(\log F_t - \log F_r) \\ = c\gamma(\log k + \log f)$$

That is, the galvanometer current depends upon f alone and is independent of any variations of the film velocity v .

The interruptions in the timing trace, of course, cause complete unbalance of the circuit. The result is that the record produced as in Figure 4 will comprise a wavy trace 123 corresponding to the variations in properties of the strata, from which there will extend marks 125, generally completely off scale, indicating a time scale along the recording trace. The resulting record of Figure 4 may be readily analyzed in conventional fashion.

While logarithmic response circuits of the type indicated in Figure 3 are theoretically necessary to balance out completely the effects of speed variations, it is to be remembered that the speed variations may be kept low. Consequently, it is satisfactory from the practical standpoint to provide a balanced analyzing circuit in which the effects of variations in speed may be minimized and made negligible with respect to the variations due to different strata.

One circuit for accomplishing this and making more satisfactory use of vacuum tubes or gas-filled tubes is illustrated in Figure 5. In this case the two photoelectric cells 126 and 128 arranged in an optical system the same as that of Figure 3, are connected in conventional fashion in the grid circuits of two vacuum tubes 130 and 132 provided with plate resistors 136 and 138 having their plates connected through a recording galvanometer or recording potentiometer 134, which is thus arranged to provide a differential reading. With the arrangement as in Figure 5, the plate currents and hence the voltage drops across the resistors 136 and 138 are proportional to the amount of light reaching the respective phototubes. The balanced arrangement illustrated, however, though not eliminating the effect of variations of the film, minimizes the effect of low variations as may be seen from the following:

The current through the galvanometer will be given by

$$i_g = I v^{-\gamma} (1 - f^{\gamma})$$

Partially differentiating with respect to v and then with respect to f and taking the quotient:

$$\frac{\partial i_g}{\partial v} = \frac{1 - f^{\gamma}}{f^{\gamma-1}} \cdot v^{-1} \\ \frac{\partial i_g}{\partial f}$$

Obviously if f^{γ} is made closely equal to unity for average conditions, this ratio may be made quite small, or in other words, the variations due to film speed changes are negligible relative to those due to different strata. On the other hand, if the circuit is not balanced, i. e. variations in the recording trace alone are recorded, the ratio becomes

$$\frac{f^{\gamma}}{f^{\gamma-1}} \cdot v^{-1}$$

which may be relatively large.

Instead of using vacuum or gas type photo-

electric cells, self-generating photocells may be used in a balanced circuit arrangement, as illustrated in Figure 6, in which it will be noted that two self-generating photocells 140 and 142 are arranged in opposition in series with a recording galvanometer or potentiometer 144. The photocells are, of course, connected in the same type of optical system as that illustrated in Figure 3, and when so arranged effect the same minimizing of variations in film speed as in the case of the arrangement of Figure 5.

From the above, it will be noted that a variable density type of record is made to give an accurate indication of the variations of film speed occurring during the recording process. It will be obvious that the invention is applicable not only to high frequency systems, but also to other electrical logging arrangements of known type.

What we claim and desire to protect by Letters Patent is:

1. The method of determining the location and character of strata penetrated by a bore hole comprising lowering a detecting device in the bore hole, recording by variable exposure of a moving sensitized film variations in the properties of the strata traversed by the detecting device, developing the film to provide a variable density trace corresponding to said variable exposure, and providing by scanning said trace by a recording photosensitive apparatus a record in the form of a curve corresponding to said variable density trace.

2. The method of determining the location and character of strata penetrated by a bore hole comprising lowering a detecting device and a casing containing recording apparatus in the bore hole, recording within the casing by variable exposure of a moving sensitized film variations in the properties of the strata traversed by the detecting device, developing the film to provide a variable density trace corresponding to said variable exposure, and providing by scanning said trace by a recording photosensitive apparatus a record in the form of a curve corresponding to said variable density trace.

3. The method of determining the location and character of strata penetrated by a bore hole comprising lowering a detecting device in the bore hole, recording by variable exposure of a moving sensitized film variations in the properties of the strata traversed by the detecting device, simultaneously exposing portions of the film to a substantially constant source of illumination, developing the film to provide a variable density trace corresponding to said variable exposure and a trace corresponding to said source of illumination, and simultaneously scanning simultaneously exposed portions of both of said traces by a recording photosensitive apparatus arranged to balance said traces against each other and provide a record corresponding to the variable density trace but substantially corrected for variations due to irregular film movements.

4. The method of determining the location and character of strata penetrated by a bore hole comprising lowering a detecting device in the bore hole, recording by variable exposure of a moving sensitized film variations in the properties of the strata traversed by the detecting device, simultaneously exposing portions of the film to a substantially constant source of illumination, developing the film to provide a variable density trace corresponding to said variable exposure and a trace corresponding to said source of illumination, and simultaneously scanning simultaneously

exposed portions of both of said traces by a recording photosensitive apparatus arranged to balance said traces against each other and provide a record in the form of a curve corresponding to the variable density trace but substantially corrected for variations due to irregular film movements.

5. The method of determining the location and character of strata penetrated by a bore hole comprising lowering a detecting device and a casing containing recording apparatus in the bore hole, recording by variable exposure of a moving sensitized film variations in the properties of the strata traversed by the detecting device, simultaneously exposing portions of the film to a substantially constant source of illumination, developing the film to provide a variable density trace corresponding to said variable exposure and a trace corresponding to said source of illumination, and simultaneously scanning simultaneously exposed portions of both of said traces by a recording photosensitive apparatus arranged to balance said traces against each other and provide a record corresponding to the variable density trace but substantially corrected for variations due to irregular film movements.

6. The method of determining the location and character of strata penetrated by a bore hole comprising lowering a detecting device in the bore hole, recording by variable exposure of a moving sensitized film variations in the properties of the strata traversed by the detecting device, simultaneously exposing portions of the film to a substantially constant source of illumination modified at intervals to indicate times, developing the film to provide a variable density trace corresponding to said variable exposure and a trace corresponding to said source of illumination, and simultaneously scanning simultaneously exposed portions of both of said traces by a recording photosensitive apparatus arranged to balance said traces against each other and provide a record corresponding to the variable density trace, but substantially corrected for variations due to irregular film movements and containing time markings.

7. The method of determining the location and character of strata penetrated by a bore hole comprising lowering a detecting device and a casing containing recording apparatus in the bore hole, recording within the casing by variable exposure of a moving sensitized film variations in the properties of the strata traversed by the detecting device, simultaneously exposing portions of the film to a substantially constant source of illumination modified at intervals to indicate times, developing the film to provide a variable density trace corresponding to said variable exposure and a trace corresponding to said source of illumination, and simultaneously scanning simultaneously exposed portions of both of said traces by a recording photosensitive apparatus arranged to balance said traces against each other and provide a record corresponding to the variable density trace but substantially corrected for variations due to irregular film movements and containing time markings.

8. Apparatus for the analysis of a record comprising a variable density photographic trace made on a moving film simultaneously with a trace formed on portions of the film by exposure to a substantially constant source of illumination, comprising a pair of photosensitive cells, means for projecting a light beam through the first mentioned trace upon one of said cells,

means for projecting a light beam through the second mentioned trace upon the other of said cells, and means connected to said cells responsive to the difference of the logarithms of the intensities of the light transmitted to the photo-cells by the respective traces.

9. Apparatus for the analysis of a record comprising a variable density photographic trace made on a moving film simultaneously with a trace formed on portions of the film by exposure to a substantially constant source of illumination, comprising a pair of photosensitive cells, means for projecting a light beam through the first mentioned trace upon one of said cells, means for projecting a light beam through the second mentioned trace upon the other of said cells; and means connected to said cells and responsive to variations in differential light transmission of said traces, whereby there are substantially eliminated from the responses effects of variable speed of the film during the making of a record.

10. Apparatus for the analysis of a record comprising a variable density photographic trace made on a moving film simultaneously with a trace formed on portions of the film by exposure to a substantially constant source of illumination, comprising a pair of photosensitive

cells, means for projecting a light beam through the first mentioned trace upon one of said cells, means for projecting a light beam through the second mentioned trace upon the other of said cells, and means connected to said cells and responsive substantially solely to those variations in the density of the first mentioned trace which are not due to the effects of variable speed of the film during the making of a record.

11. Apparatus for the analysis of a record comprising a variable density photographic trace made on a moving film simultaneously with a trace formed on portions of the film by exposure to a substantially constant source of illumination, comprising a pair of photosensitive cells, means for projecting a light beam through the first mentioned trace upon one of said cells, means for projecting a light beam through the second mentioned trace upon the other of said cells, and means connected to said cells for providing a record in the form of a curve corresponding substantially only to variations in density of the first mentioned trace other than those which may be due to variable speed of the film during the making of a record.

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