

**July 25, 1961**

**E. T. HOWES**  
**WELL LOGGING SYSTEM**

**2,993,553**

Filed May 9, 1955

5 Sheets-Sheet 1

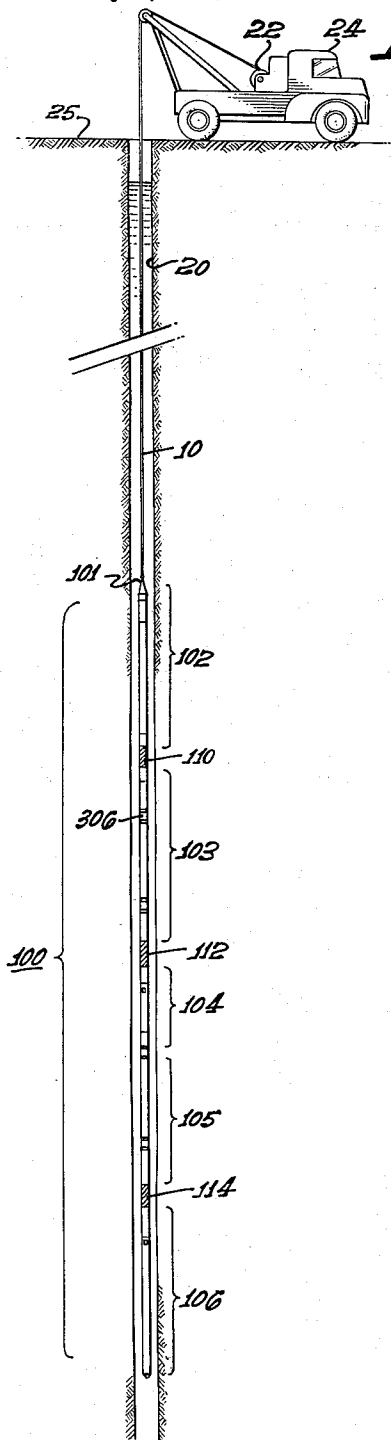


FIG. 1.

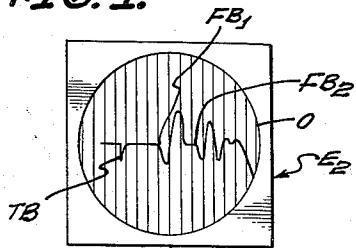
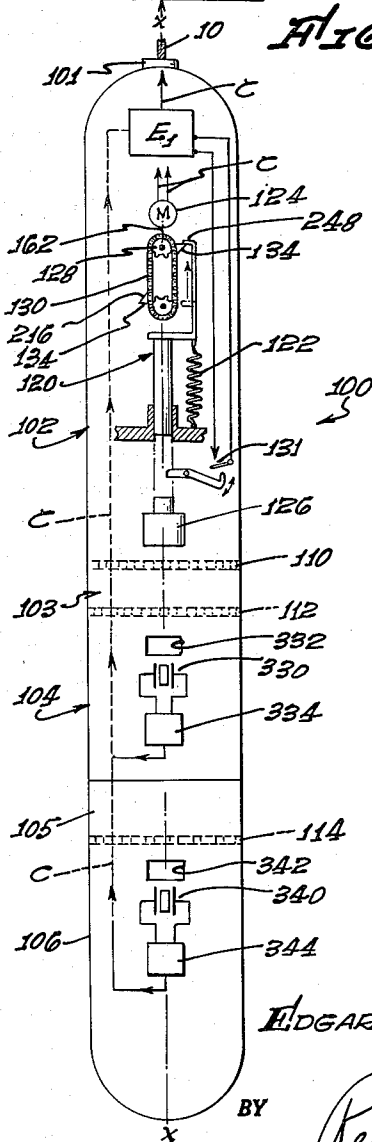


FIG. 2.



**EDGAR T. HOWES,**  
INVENTOR.

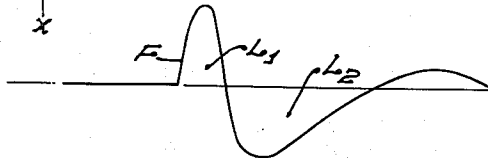
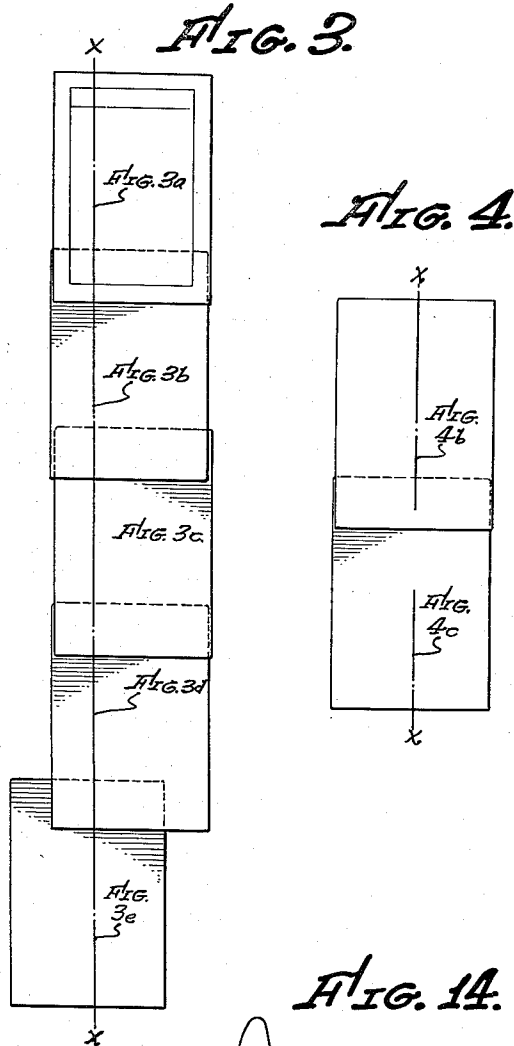
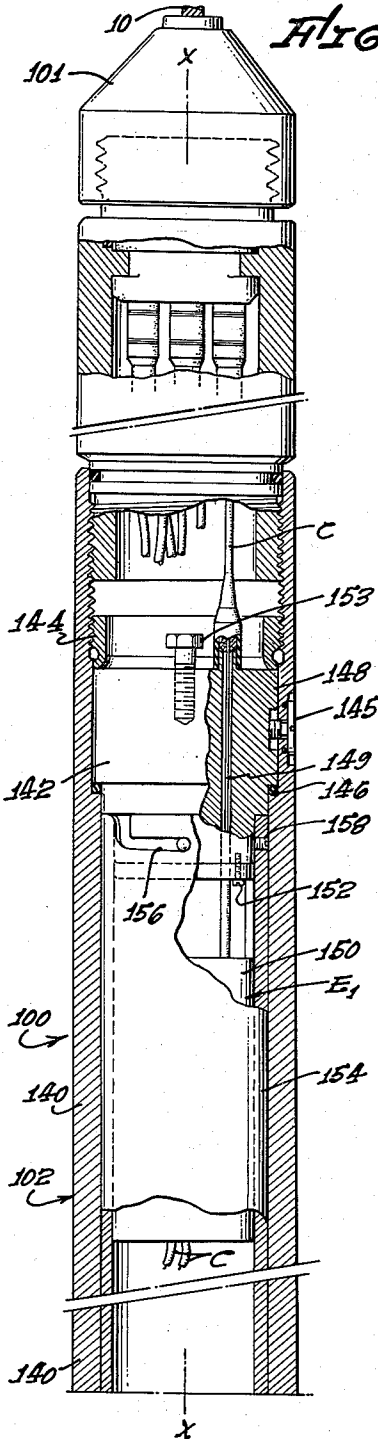
**BY**

Reed G Lawlor  
ATTORNEY.

**E. T. HOWES**  
**WELL LOGGING SYSTEM**

Filed May 9, 1955

FIG. 3a.



**EDGAR T. HOWES,**  
INVENTOR.

**BY**

Red Lawlor  
ATTORNEY.

July 25, 1961

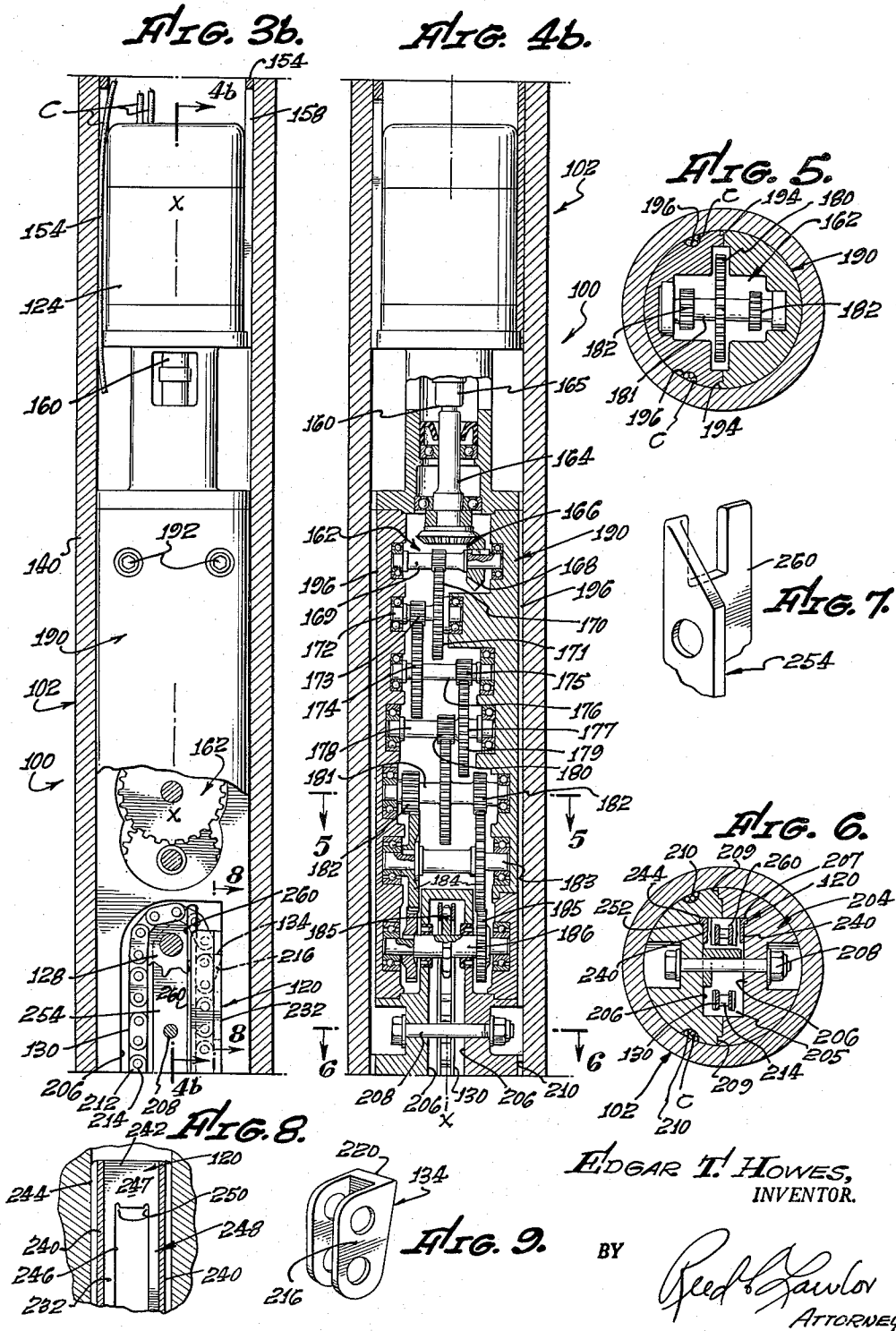
E. T. HOWES

2,993,553

WELL LOGGING SYSTEM

Filed May 9, 1955

5 Sheets-Sheet 3



July 25, 1961

E. T. HOWES

2,993,553

WELL LOGGING SYSTEM

Filed May 9, 1955

5 Sheets-Sheet 4

FIG. 3c.

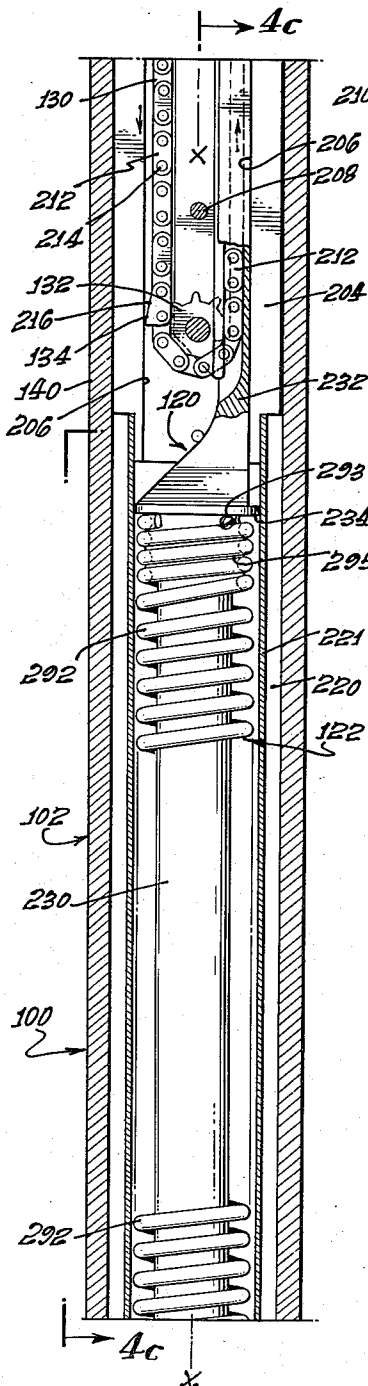


FIG. 4c.

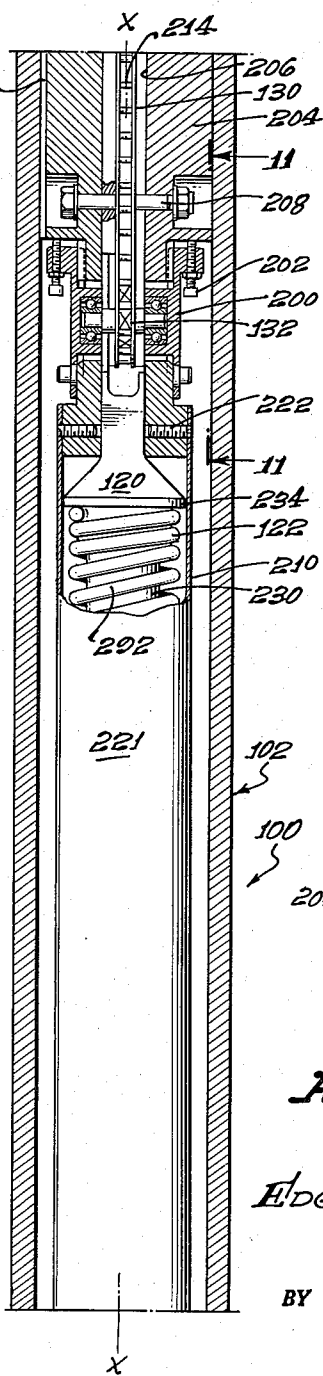


FIG. 10.

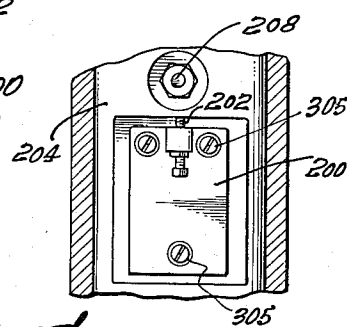
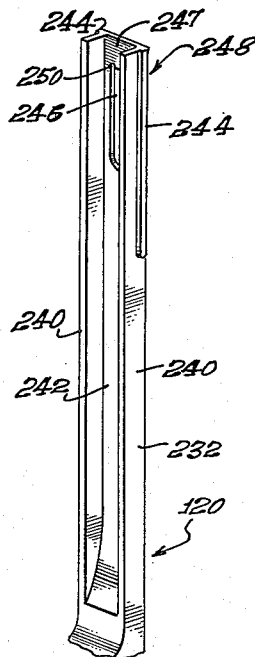


FIG. 11.

EDGAR T. HOWES,  
INVENTOR.

BY

*Reed G. Lawlor*  
ATTORNEY

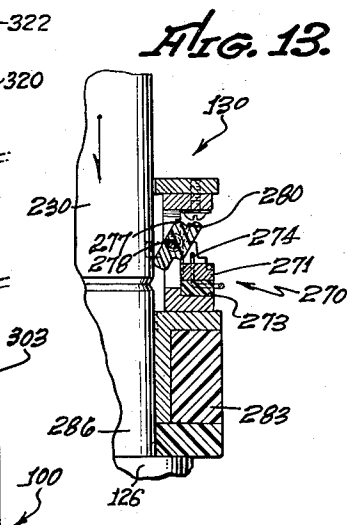
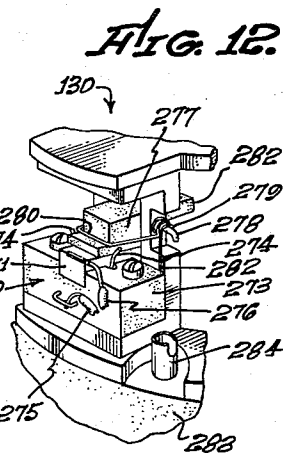
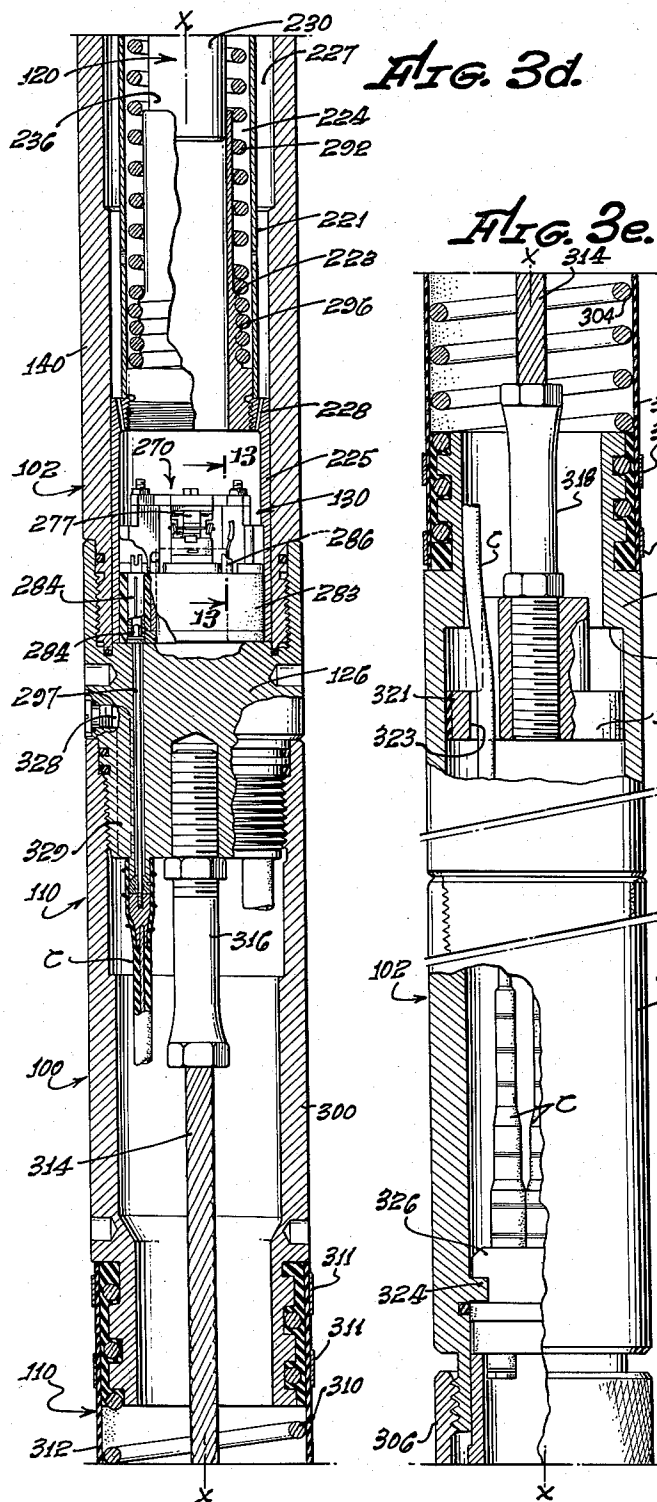
July 25, 1961

E. T. HOWES  
WELL LOGGING SYSTEM

2,993,553

Filed May 9, 1955

5 Sheets-Sheet 5



EDGAR T. HOWES,  
INVENTOR.

BY

Reed G. Lawton  
ATTORNEY

1

## WELL LOGGING SYSTEM

Edgar T. Howes, Pasadena, Calif., assignor to United Geophysical Corporation, Pasadena, Calif., a corporation of California

Filed May 9, 1955, Ser. No. 506,819

14 Claims. (Cl. 181—5)

This invention relates to improvements in systems for logging wells and more particularly to improvements in systems for logging the seismic wave characteristics, especially the seismic wave interval velocity characteristic, of formations intersected by a well. More specifically the invention relates particularly to an improved arrangement for generating and receiving seismic waves in a well during a logging operation. This application is a continuation-in-part of my copending patent application Serial No. 462,062, filed October 13, 1954.

Generally speaking, two types of systems have been developed for logging the velocity characteristics of formations penetrated by a well. One type involves the continuous generation of seismic or acoustic waves of constant amplitude and frequency at a source and the continuous reception of these waves at a receiver. The source and the receiver are moved along the length of a well together, and either changes in amplitude or phase of the received waves are measured at intervals to provide an indication of changes in the characteristics of the surrounding formations as the source and receiver are moved along the length of the well. A system of this type is described in Cooper patent No. 2,156,052. In the other type, a seismic wave transmitter is employed to generate a transient seismic wave train, or seismic wave impulse of short duration, and such a wave is received at one or more points spaced from the transmitter. The transmitter and the receiver, or receivers, are moved together along the length of the well, and the transmitter is periodically operated to facilitate the measurement of characteristics of the formation at various depths in the well.

Systems of this type are disclosed in the Wyckoff and Vogel patents specifically referred to hereinafter.

Various types of transmitters have been employed as sources of such seismic wave impulses. One type of transmitter employs an explosive charge to generate the seismic impulse. One disadvantage of the use of such an explosive charge to generate the seismic wave impulse resides in the fact that only a limited number of explosive charges can be carried in any well surveying device so that it becomes extremely difficult and expensive to make a continuous survey of a seismic wave characteristic over a great depth range in a well. In other systems, the transmitter has assumed the form of a flexible metallic diaphragm arranged in the wall of a source of transmitter, and some sort of means, such as an electromagnet, is arranged to cause the diaphragm to be displaced suddenly in order to impart a seismic wave impulse to the fluid in the well. Devices of this type are illustrated in Patent No. 2,233,992 which issued to Ralph D. Wyckoff March 4, 1941. In another type of transmitter an electric spark has been periodically generated by the discharge of electricity between a pair of electrodes to generate a seismic wave impulse. Such a device is illustrated in Patent No. 2,651,027 which issued to Charles B. Vogel September 1, 1953. Electromagnet and spark-type transmitters have not been very effective because of the fact that it is very difficult to produce seismic wave impulses of great strength or high amplitude. For this reason, it is very difficult to make reliable and accurate logs of seismic wave characteristics with them under widely varying conditions such as those normally encountered in surveying wells.

In copending patent application Serial No. 462,062

2

filed by me October 13, 1954, there is disclosed and claimed a logging system which employs a well unit comprising a seismic wave generator or transmitter and a pair of seismic wave receivers, all arranged within a common housing or casing, for use in making interval velocity logs. In that application I have disclosed a system in which seismic wave impulses are periodically generated at a transmitter and periodically received at the receivers as the well unit is raised or lowered in the well. An electric trigger pulse is generated each time a seismic wave impulse is generated. The trigger pulse is employed in the well unit to switch the output of the two receivers so that they are connected to common lines in the cable at the respective times that the seismic waves are received at the respective receivers. The trigger pulse and the electric waves generated in the receivers are both transmitted to the surface, where they are displayed on a common trace on the face of an oscilloscope together with timing lines for measuring the time elapsed between the creation of the electric impulse and the times of reception of the seismic waves at the respective receivers.

The present invention relates particularly to an improved well unit for use in logging the interval velocity or other seismic wave characteristic of a well and which is particularly suited for use in the system of copending application Serial No. 462,062.

The invention involves both improvements in seismic wave transmitters and improvements in a combined transmitter and receiver or receivers. By means of the improved transmitter it is possible to generate strong seismic wave impulses. By means of the improvements in the overall combination it is possible to transmit seismic wave impulses from a transmitter to a receiver or receivers through the formations very effectively compared with the transmission by other paths, thus increasing the accuracy and reliability of the measurements.

The novel features which are considered characteristic of the invention are set forth with particularity in the appended claims. The invention itself, however, both as to its organization and its method of operation together with various features and advantages thereof, will be best understood from the following description of a specific embodiment thereof when read in connection with the accompanying drawings in which:

FIGURE 1 is a vertical cross-sectional view of the earth showing a well being surveyed with the well testing unit of this invention;

FIG. 2 is a schematic diagram of the well testing equipment;

FIGS. 3a, 3b, 3c, 3d, and 3e represent successive segments of the upper part of the well testing unit;

FIG. 3 is a diagram showing how the drawings of FIGS. 3a, 3b, 3c, 3d, and 3e are assembled to illustrate the upper part of the well testing unit;

FIGS. 4b and 4c are sectional views taken on the lines 4b—4b and 4c—4c of FIGS. 3b and 3c respectively, of certain segments of the well testing unit;

FIG. 4 is a diagram showing how FIGS. 4b and 4c are assembled to form a portion of the upper part of the well testing unit;

FIG. 5 is a horizontal cross-sectional view taken on the line 5—5 of FIG. 4b;

FIG. 6 is a cross-sectional view taken on the line 6—6 of FIG. 4b;

FIG. 7 is a fragmentary perspective view of the chain backing member;

FIG. 8 is a cross-sectional view taken on the line 8—8 of FIG. 3b;

FIG. 9 is a perspective view of a hammer cocking member;

FIG. 10 is a fragmentary perspective view of the hammer hook;

FIG. 11 is a side elevational view taken on the line 11—11 of FIG. 4c;

FIG. 12 is a fragmentary perspective view of the switch;

FIG. 13 is a cross-sectional view taken on the line 13—13 of FIG. 3d; and

FIG. 14 is a graph of a seismic wave impulse of the type generated by the transmitter.

In the form of the invention illustrated in FIGS. 1 and 2, an elongated well testing unit 100 supported by a cable 10 is raised and lowered in a well 20 by means of a winch 22 carried by a truck 24 at the surface 25 of the earth. The well unit 100 includes a cable connector 101, a seismic wave generator or transmitter 102, a first spacer 103, a first or an upper seismic wave receiver 104, a second spacer 105, and a second or lower seismic wave receiver 106, all arranged in the order named from top to bottom. The well unit 100 is attached to the lowermost end of the cable 10 by means of the coupler 101. The unit is arranged in an elongated housing which in practice is composed of a series of housing members or sections which house separate parts of the well unit.

A first or upper flexible coupling device 110 is arranged between the transmitter 102 and the first spacer 103, a second or intermediate flexible coupling device 112 is arranged between the first spacer 103 and the upper receiver 104 and a third or lower flexible coupling device 114 is arranged between the upper and lower receivers 104 and 106. The transmitter 102, the spacers 103 and 105, the two hydrophones 104 and 106, and the coupling devices 110, 112, and 114 are arranged coaxially along an axis  $x-x$ , such as a vertical line, in the order named, with the transmitter above the hydrophones and with the upper hydrophone 104 located midway between the transmitter 102 and the lower hydrophone 106. As will become apparent hereinafter, the coupling devices 110, 112 and 114 act as vibration filters to attenuate and delay direct transmission of energy from the transmitter 102 to either receiver 104 or 106 or from one receiver to the other. At the same time though the upper coupling device 110 closely couples the transmitter with liquid such as oil or mud in the well so as to facilitate transmission of seismic energy through the surrounding formations to the receivers.

The seismic wave transmitter 102 includes special means for periodically radiating a seismic wave impulse into the liquid in which the well unit is immersed and into the surrounding formations 14 through which the well extends, as described more fully hereinafter. The two seismic wave receivers 104 and 106 are in the form of hydrophones which respond to waves which travel thereto either directly by a path through the fluid within the well from the seismic wave transmitter 102 or indirectly thereto after being transmitted through the formations forming the walls of the well 20. Inasmuch as the velocity of transmission of sound through the formations is almost invariably greater than the velocity of transmission of sound through the well liquid, by spacing the transmitter and the receivers far enough apart, waves transmitted from the transmitter through the formations arrive at the receivers before the waves transmitted through the liquid and the latter waves do not interfere with the detection of the arrival of the former. However, unless precautions are taken in accordance with this invention, vibrations transmitted through the housing might arrive at a receiver before the waves travelling through the formations and interfere with the detection of the first arrivals of the latter at the receiver.

In the system described specifically in my copending patent application Serial No. 462,062, the well unit 100 also includes certain subsurface electrical equipment  $E_1$  and certain surface electrical equipment  $E_2$  that is located at the surface and is connected thereto through the cable 10 as shown in FIG. 2. This equipment is employed for transmitting to the surface unit a "time break" sig-

nal TB that indicates the instant of operation of the transmitter and other signals FB1 and FB2 that correspond to the first breaks of seismic waves that are received by the hydrophones 104 and 106 and that indicate the instants of arrival of waves at the hydrophones 102 and 104. The electrical units  $E_1$  and  $E_2$  operate to display the time break TB and first breaks FB1 and FB2 on a single trace of an oscilloscope O, the three first breaks corresponding to the instants at which the trigger pulse is generated and the instants at which seismic wave pulses are first received at the receivers 104 and 106. This record also displays a plurality of vertical timing lines T to facilitate measurement of the time of travel of seismic waves from the transmitter 102 to each of the receivers 104 and 106. The details of the subsurface electrical equipment  $E_1$  and the surface electrical equipment  $E_2$  which are employed to produce a series of such records at various depths in a well are described in said copending patent application Serial No. 462,062.

As illustrated very schematically in FIG. 2, the seismic wave source, or transmitter, 102 of this invention comprises a hammer 120 which is normally urged toward the downward or lowermost position by means of a strong extension spring 122. A D.C. electric motor 124 driven by electric power supplied from the surface through the cable 10 is employed to slowly raise the hammer 120 periodically to its uppermost position and to release it periodically to cause the hammer 120 to strike an anvil 126 that is disposed directly beneath the hammer 120 and is rigidly secured to the housing member of the transmitter 102.

The mechanism for raising and releasing the hammer 120 includes a chain 130 that passes over a driving sprocket 128 and over a driven sprocket 132. The driving sprocket 128 is driven by the motor 124 through a gear train 162. The chain 130 carries a pair of outwardly projecting cocking members in the form of fingers 134 which are located at equally spaced positions on the chain. As each of the fingers 134 passes upwardly adjacent the hammer 120, it engages a hook 248 on the hammer thereby forcing the hammer upwardly against the force of the spring 122 and storing potential energy in the spring 122 and in the hammer 120. When each of the fingers 134 reaches its uppermost position and withdraws from the hammer 120, it becomes disengaged from the hook 248 thereby releasing the hammer and permitting the spring to force the hammer 120 downward rapidly to strike the anvil 126. The motor 124 is driven continuously, thereby causing the hammer to strike the anvil 126 periodically at regular short intervals of time such as once every five seconds. Each time the hammer 120 strikes the anvil 126 it also closes a normally open switch 131 to generate a trigger pulse which is employed to operate the subsurface electrical equipment  $E_1$  and the surface electrical equipment  $E_2$ , as described more fully in my copending patent application Serial No. 462,062.

As the cable 10 is raised or lowered in the well, the well unit 100 passes through various formations which are characterized by different seismic wave velocities. Each time the hammer 120 strikes the anvil 126 a seismic wave impulse is transmitted outwardly from the seismic wave generator and into the surrounding formations through which they travel to the seismic wave receivers 104 and 106. Seismic wave energy which has traveled through the adjacent formation reenters the well, arriving at the hydrophones 104 and 106 at spaced time intervals. By recording the time break TB and the first breaks FB1 and FB2 each time a seismic wave is generated, a record such as that shown in Fig. 2 is produced. By measuring the depth at which the well unit is located at the time that each record is produced as the cable is moved along the length of the borehole, a seismic wave interval velocity log is obtained.

5

The well unit 100, and more particularly the seismic wave transmitter 102, will now be described in some detail generally following a sequence from top to bottom. In this connection it is to be noted that the details of a complete seismic wave transmitter 102, together with certain associated parts, are illustrated in FIGS. 3a, 3b, 3c, 3d, and 3e, and in part in FIGS. 4b and 4c. The seismic wave transmitter 102 comprises a tubular housing member 140 which is connected at its upper end to the cable connector 101 as shown in FIG. 3a and at its lower end to the upper coupling 110 as shown in FIG. 3d. The anvil 126 is arranged as shown in FIG. 3d at the junction between the transmitter 102 and the upper coupling device 110. Suitable means are employed for leading conductors, designated only in a general way by the symbol C, from the cable 10 through the cable connector 101 into the housing section 140 and through the anvil 126, the coupling device 110, the receiver 104, the coupling device 112, and to the lower receiver 106 as needed. In any event, the housing member 140 of the transmitter 102 is filled with air or some inert gas and is sealed by suitable means to render it fluid-tight to prevent leakage of well fluid into the transmitter even at the high pressures encountered at depths of 10,000 feet or more in a deep well. But the coupling device 110, which is also of hollow tubular configuration, is filled with oil or some other suitable liquid and is sealed to render it fluid-tight to prevent leakage of well fluid into it when in a well and to prevent leakage of air into it when the well unit is exposed to the atmosphere at the surface and generally to prevent leakage of the oil or other liquid from the coupling device at all times.

A billet 142 locked by means of a lock nut 144 and sealed by an O-ring 146 is rigidly secured to the upper end of the housing member 140, sealing it against leakage of air or ingress of liquid. The billet 142 is provided with a plurality of longitudinal passages 148 through which various conductor sections 149 extend, these conductor sections being sealed in place in some suitable fashion to render the passages 148 fluid-tight. A cylindrical container 150 which encloses the subsurface electrical unit E<sub>1</sub> is securely fastened to the lower end of the billet 142 by some suitable means such as screws 152. A screw 153 at the top of billet 142 facilitates its insertion and removal. A spacer sleeve 154 is securely fastened to the lower end of the billet 142 by means of a bayonet lock 156 and a set-screw 158. The spacer sleeve 154 is designed to fit closely between the case 150 and the housing member 140.

As shown in FIGS. 3b and 4b, the motor 124 is located at the bottom end of the spacer sleeve 154. Certain conductors C that are connected with the cable 10 are employed to supply D.C. current to the motor 124. Slots 158 formed in the lower end of the spacer sleeve 154 facilitate the passage of other conductors C downwardly past the motor 124 to points where connections thereto are needed in the well unit.

As shown in detail in FIGS. 3b and 4b, the drive shaft 160 of the motor 124 drives the driving sprocket 128 through a speed-reducing gear train 162. The input shaft 164 of the gear train is connected through a suitable coupling 165 to the motor drive shaft 160, the input shaft 164 and the motor shaft being coaxially and longitudinally mounted within the housing member 140. A driving bevel gear 166 at the lower end of the input shaft 164 engages a driven bevel gear 168 mounted on a first horizontal or transverse shaft 169. A small spur gear 170 mounted at the center of the shaft 169 drives a large gear 171 on a second horizontal or transverse shaft 172. A spur gear 173 on the shaft 172 engages a large gear 174 on a third horizontal or transverse shaft 175. Likewise, a small spur gear 176 on the shaft 175 engages a large gear 177 on a fourth transverse or horizontal shaft 178. Similarly, a spur gear 179 on the shaft 178 engages a large driven gear 180 at the center of a

6

fifth transverse or horizontal shaft 181. Spur gears 182 at the opposite ends of the shaft 181 engage large idler gears 184 arranged on opposite ends of a sixth horizontal or transverse shaft 183, the idler gears in turn engaging driven gears 185 at opposite ends of a seventh horizontal shaft 186 which carries the driving sprocket 128. All of the horizontal shafts are arranged in suitable ball bearings mounted within a cylindrical housing 190, the shafts being arranged one beneath the other in the order named in a common central longitudinal plane.

As shown in FIG. 5, the housing 190 is split, being formed of two very similar semi-cylindrical parts which are rigidly secured together by bolts 192 (see FIG. 3b) and aligned by means of mating flanges 194. Channels 196 formed in the outer surface of the gear housing 190 are employed to permit the passage of electrical conductors C past the gear housing.

It will be noted that as power passes through the gear train, the speed is reduced as movement is imparted from one shaft to another successively. However, as the speed of rotation of the shafts decreases from shaft to shaft, the torque applied to the gears increases. By employing gears at both ends of the lower shafts 181 and 186 strain on the individual gear teeth on these shafts is reduced. One of the idler gears 184 is keyed to the shaft 183, while the other is permitted to rotate freely thereon so as to minimize any danger of misfit or excessive wear between the upper pair of gears 182 and the lower pair of gears 185 which engage the idler gears.

The driven sprocket 132 is mounted, as shown more particularly in FIGS. 4c and 11, on a bearing support 200 which may be adjusted in position longitudinally within the housing 140 by means of adjusting screws 202 which engage the lower end of a guide block 204 which in turn engages the lower end of the gear housing 190. After adjustment, the bearing support is locked in place by means of screws 305.

As shown more particularly in FIG. 6, the guide block 204 is split, being divided into two similar sections in which facing grooves 206 form a rectangular passage 205 extending from one end of the guide block 204 to the other. The two sections of the guide block 204 are rigidly secured together by means of mating flanges 209 and suitable bolts 208. The guide block is also provided with external passages 210 to permit the passage of conductors C. The rectangular passage 205 is sufficiently large to permit the chain 130 to move freely therein when driven by the driving sprocket 128. The guide block 204 serves not only to support the chain 130 but also to guide the hammer in its up and down path as more fully described below. The guide block 204 thus acts as an upper hammer guide.

The chain 130 consists of a series of conventional links 212 connected by pins 214 for engaging the sprockets 128 and 132. However, two of the links 216, illustrated in detail in FIG. 9, are provided with tapered fingers or extensions having broad abutments 220 at the leading edges thereof. The two extended links 216 are located half a chain length apart and are used as cocking members or fingers for raising and releasing the hammer 120 as described more fully hereinbelow.

An intermediate hammer guide 221 in the form of a tubular member or cylinder is fastened by means of screws 222 to the lower end of the upper hammer guide 204. The lower end of the intermediate guide 221 is centered in the housing member 140 by means of a lower hammer guide 223 which is in the form of a tubular member or cylinder of smaller diameter which extends into the cylinder 221. The upper end of the tubular member 223 is spaced from the tubular member 221 forming an annular space 224 between the intermediate and lower hammer guide members 221 and 223. A spacer 225 that threadably engages the lower end of the lower hammer guide 223 engages the lower end of the intermediate guide 221 and it is seated at its lower end against the upper surface of the anvil 126. The outside

diameter of the cylinder 221 is smaller than the inside diameter of the housing member 140, thereby providing an annular space 227 through which various conductors may pass, the lower ends of the conductors extending through inclined passages 228 at the upper end of the spacer 225. The conductors fit only loosely in the passages 297 thereby permitting air to flow freely there-through when the hammer is raised and lowered.

The hammer 120 itself is of unitary construction, being provided with a heavy elongated cylindrical body or core 230 at its lower end and a relatively light rectangular arm 232 extending upwardly from its upper end. An outwardly extending flange 234 between the body 230 and the arm 232 slidably engages the inner surface of the intermediate hammer guide 221, while the foot 236 at the lower end of the body 230 slidably engages the inner surface of the lower hammer guide 223. Holes in the lower end of the intermediate hammer guide 221 permit the free flow of air therethrough during the operation of the hammer.

The hammer arm 232 is milled out to form a U-shaped member comprising two straight parallel legs 240 connected together by means of flat webbing 242. A pair of outwardly extending ears or rails 244 are formed at the upper end of the arm 232. An opening or window 246 cut in the upper end of the webbing 242 terminates in a bridge 247 thus forming a hammer hook 248. To increase the strength and durability of the hammer arm in operation, all surfaces of the hammer arm 232 are finished to a smoothness of at least about 16 $\mu$  inch R.M.S. and the surface is rendered substantially free from irregularities that would be visible to the average eye at a distance of about 18 inches. The irregularities thus removed include scratches, pit holes, or other indentations and also large or sharp protrusions. Furthermore, to increase the strength of the hammer arm 232, the upper corners of the window 246 are notched as indicated at 250 in FIG. 8, and the various edges of the hammer arm, especially those at the edges of the window are rounded to eliminate sharp edges. The radius of curvature of the rounded portions should be at least about 0.01 inch.

The hammer arm 232 extends upwardly along one side of the rectangular window 207 of the upper hammer guide 204. As indicated in FIG. 6, the legs 240 of the hammer arm 232 slidably engage the side walls of the passage 205 and the ears or rails 244 slidably engage grooves 252 at the corners of the passage 205. A support member 254 of L-shape, as indicated in FIGS. 6 and 7 as well as in FIGS. 3b and 3c, provides a backing plate 260 to assist in preventing excessive inward flexure of the chain 130 during operation while it is raising the hammer 120, thereby preventing the hammer hook 248 from slipping inadvertently from the finger 218 during operation.

An electric switch 270 is mounted at the upper end of the anvil 126 where it may be operated each time the hammer 120 is released to strike the anvil. As shown in more detail in FIG. 12, the switch 270 comprises a stationary electrical contact 271 mounted on a block 273 of insulation material and a pair of resilient movable contacts 274 on opposite sides thereof. The stationary contact 271 is connected to one conductor 275 and the pair of movable contacts are connected to another conductor 276. The two resilient movable contacts 274 are normally held apart in spaced relationship from the stationary contact 271 by an insulating arm 277 which is arranged to rotate about a horizontal axis established by a pin 278. A torsion spring 279 normally pivots the insulating arm 277 to a horizontal position where an outwardly extending finger 280 rests upon the stationary contact 270 and holds the movable contacts 274 in their open circuit position spaced from the stationary contact 271. An inwardly extending finger 282 of the arm 277 projects across the path of the hammer body 230 so that when the hammer is lowered, it pushes the inwardly ex-

tending finger 282 downwardly, lifting the outwardly extending finger 280 off the stationary contact 271, permitting the resilient movable contacts 274 to contact the stationary contact 271, thereby closing a circuit to create a trigger pulse for use in the operation of the subsurface and the surface electrical units  $E_1$  and  $E_2$ .

A cylindrical insulation ring 283, on which the switch 270 is mounted, is provided with suitable connectors 284 for joining parts of the electrical conductors C that pass through the anvil 126. Passages 297 extending longitudinally through the anvil are provided to permit the leading of conductors through the anvil 126 to the receivers 104 and 106. An upwardly projecting head 286 of the anvil 126 extends upwardly through the ring 284 and terminates just beneath the switch operating arm 277 as indicated in FIG. 13, so that when the hammer approaches the anvil the trigger pulse created by the closure of the switch 146 is produced simultaneously with the initial impact of the hammer on the anvil.

A helical spring 292 encircles the hammer body 230. The upper end of the helical spring is anchored by a rivet or pin 293 to the upper end of the hammer body 230 directly beneath the flange 234, and the other end of the spring is attached to the outer end of the lower hammer guide 223. The turns of the helical spring 292 between the ends thereof are normally spaced apart. However, a few turns at the upper end and a few at the lower end are closely spaced and are arranged to engage helical grooves 295 in the hammer body and grooves 296 in the lower hammer guide 223.

The coupling device 110 is an improvement in the type described and claimed in my copending patent application Serial No. 366,271, now Patent No. 2,788,510. The coupling device 110 comprises upper and lower tubular connectors 300 and 302 and an interconnecting resilient member 304. The upper tubular connector 300 threadably engages the lower end of the anvil 126. The lower tubular connector 302 threadably engages a connector 306 which facilitates connection of the transmitter 102 to the spacer 103.

The interconnecting resilient member 304 comprises a helical spring 310 which is threaded onto the lower end of the upper tubular connector 300 and onto the upper end of the lower tubular connector 302, being locked thereon by bodies of rubber which are cured in place on the threaded parts of the spring. The resilient member 304 also includes a protective elastic sleeve 312 composed of rubber or other suitable material which encloses the spring 310. The rubber sleeve 312 is clamped in place about the threaded ends of the spring 310 by means of straps 311 and 313.

The upper end of a stretch limit member 314 is connected by a bolt 316 to the anvil member 126. The lower end of the stretch limit member 314 is connected by a bolt 318 to a piston 320 which is slidably mounted within the lower tubular connector 302. A rubber ring 321 bonded onto the outer rim of the piston 320 prevents metal-to-metal contact between the piston and the lower tubular connector 302. A shoulder 322 formed in the lower tubular connector 302 limits the upward movement of the piston 320 therein, thereby limiting the extension or stretching of the resilient member 304 including the spring 310 and the elastic sleeve 312. Holes 323 formed in the piston 320 facilitate the leading of conductors downwardly to the receivers 102 and 104.

The lower tubular connector 302 includes a threadably removable section 303 which is threaded directly into a connector 306 at the top of the upper spacer 103. The connector section 303 is provided to facilitate the assembly of the tool and is provided with a bayonet connection 324 to permit locking an electrical connector 326 at its bottom end.

The entire space between the anvil 126 and the electrical connector 326 is sealed to prevent ingress or egress of fluid therefrom, and this space is filled with oil through

filler ports 328 extending laterally into the anvil 126 from opposite sides thereof and communicating with longitudinally extending passages 329 which lead into the interior of the coupling device 110. In practice the coupling device 110 is filled with oil while the coupling device is extended under load and care is exercised to eliminate air bubbles from the interior of the coupling device 110.

The coupling devices 112 and 114 are of substantially the same construction as the coupling device 110 which has been described in detail in connection with Figs. 3d and 3e.

Each of the spacers 103 and 105 comprises a tubular housing member which is connected in any suitable manner between the transmitter 102 and the receivers 104 and 106.

Each of the receivers 104 and 106 is in the form of a hydrophone of the type described and claimed in co-pending patent application Serial No. 366,093 filed by Douglas G. Marlow July 6, 1953. The hydrophone 106 comprises a pressure-responsive element 330 which is in direct communication with fluid in a lateral passage 332 extending through the housing member of the hydrophone near the upper end thereof as indicated in Fig. 2. The pressure-responsive element may be in the form of a piezo-electric crystal which is connected to the input of a pre-amplifier 334. The lower receiver 106 is of a construction similar to that of the upper receiver 104, being provided with a pressure-responsive element 340 adjacent a lateral passage 342 at its upper end, and a pre-amplifier 344 connected to the element 340.

Conductors in the outputs of the pre-amplifiers 334 and 344 lead upwardly through the various sections of the testing unit to the subsurface electrical unit  $E_1$ . Thus suitable output conductors lead upwardly from the lower pre-amplifier 344 through the coupling device 114 and through the spacer 105 into the receiver 104. From there these conductors and also conductors connected to the output of the upper pre-amplifier 334 lead upwardly through the coupling device 112 and the spacer 103 into the transmitter 102 where they feed signals into the subsurface electrical unit  $E_1$ . Here a signal produced by the closing of switch 270 operates to cause signals from the outputs of the two pre-amplifiers to be transmitted through the cable 10 to the surface of the earth. Other conductors as needed are led through the various sections of the testing unit 100 to the cable 10.

Details of the spacers and the hydrophones and the electrical connections are not disclosed herein, since no claim to such details per se is made herein and since spacers and hydrophones and electrical connections may be embodied in many forms within the scope of the present invention.

To make an interval velocity log of a well, the testing unit 100 is lowered into the well by paying out the cable 10 from the winch 22. Subsequently the testing tool is raised in the well by winding up the cable 10 onto the winch 22. Either while the testing unit 100 is being lowered into the well or while it is being raised upwardly therein, power supplied from a battery or generator in the truck 24 is fed through the cable 10 to the motor 124 causing the motor to rotate continuously, thereby driving the endless chain 130 continuously. As the chain 130 is continuously moved over the sprockets 128 and 132, the extended links 216 thereon periodically engage the hook 248 of the hammer, raising the hammer against the force exerted by the helical spring 262 and extending the helical spring, thereby storing potential energy in the spring. At the top of the hammer stroke the link becomes disengaged from the hook, thereby releasing the hammer.

The hammer arm 240 is so arranged that the hook 248 lies adjacent the lower sprocket 132 whenever the hammer 120 is in its lowermost position in which the hammer engages the anvil 126. Each time one of the extended

links 216 passes near and beyond the lower sprocket 132 it engages the hook 248, thereby raising the hammer 120 upwardly, drawing it away from the anvil 126. As the hammer 120 is raised, the spring 262 is extended, thereby storing potential energy therein. As the extended link 216 that is in engagement with the hook 248 approaches and passes near the upper sprocket 128, the hook 248 is released. Upon release, the spring 262 forces the hammer downwardly, causing it to strike the anvil 126 at a relatively high speed.

In a specific embodiment of the invention employing a spring 262 having a compliance of about 20.1 lbs./in. and a hammer weighing about 3.5 lbs., when the amplitude of the hammer stroke was 0.5 ft., the hammer 120 struck the anvil 126 at a velocity of about 18'/sec. The anvil itself, in this specific embodiment of the invention weighed about 7.5 lbs., and it was rigidly secured to the lower end of a transmitter unit 102 having a total weight of about 100 lbs. The hammer and anvil were made of 6150 steel. The length of the hammer body was 14" and the length of the hammer arm was 15". The diameter of the hammer body and the head of the anvil were the same, being about 1". The overall length of the anvil was about 5½" and the diameter of the main body of the anvil was about 3½". In practice, when using a ½ H.P. D.C. electric motor to drive the chain 130 through a speed reducing gear of about 700 to 1 ratio, the hammer strikes the anvil periodically at intervals of about 5 seconds. At the same time that each seismic impulse is generated, an electric trigger pulse is created by the closing of the switch 270, and this trigger pulse is employed to operate the subsurface electrical circuit  $E_1$  and the surface electrical circuit  $E_2$  as previously mentioned.

Each time the hammer 120 is released, it strikes the anvil 126 causing a sharp seismic or acoustic impulse of short duration to be applied by the anvil 126 to the liquid in the borehole and to the neighboring formations. Though the impulse may be of widely different forms and still be effective for logging a well, it is believed that close to the anvil the seismic wave emitted is of the general shape indicated in the graph of FIG. 14. Here it will be noted that the impulse has a very steep wave front F at its beginning and that this wave front is followed by a series of lobes  $L_1$ ,  $L_2$ , etc., each of short duration and forming a seismic wave train. The duration of each of the first lobes  $L_1$ ,  $L_2$ , etc. is very short, being of the order of less than 0.0001 sec., though later lobes (not shown) may be longer duration. Such a seismic wave impulse having a steep wave front F and narrow first lobes is characterized by a broad high frequency spectrum, being rich in frequency components over a wide range from below about 1000 c.p.s. to above about 50,000 c.p.s. The presence of such high frequency components facilitates the accurate timing of first breaks to about 0.00001 sec.

The anvil 126, being thick, along its axis acts as a thick solid plate or short rod rather than as a vibratory diaphragm. For this reason the frequency characteristic of the first lobe of the impulse does not depend on the bending characteristics of the anvil as is the case with a diaphragm, but upon the velocity of transmission there-through and the length of the anvil. Furthermore, the anvil does not vibrate like a diaphragm each time it is struck. A compression wave imparted to the upper surface of the anvil travels therethrough with the speed of sound to the lower surface of the anvil. The lower surface of the anvil 126 is closely coupled to the liquid in the well and to the neighboring formation of the earth by virtue of the design of the coupling device 110. The close coupling between the anvil 126 and the liquid in the well is brought about by virtue of the fact that the lower surface of the anvil is in direct contact with the liquid contained within the coupling device 110 and by

virtue of the fact that the sleeve 312 of the coupling device is thin and elastic, and by virtue of the fact that the liquid on opposite sides of the sleeve has very near the same acoustic impedances usually differing by no more than a factor of 2 so that very little impedance is offered to the transfer of seismic or acoustic energy from the liquid in the coupling device to the liquid in the well outside the coupling device. For this reason a large amount of the energy transmitted by the hammer to the anvil is radiated as an impulse of short duration into the surrounding well liquid.

It is to be noted that when and only when the anvil is coupled to the liquid or to the formations is energy transmitted into the formations. In the specific embodiment of the invention described herein, close coupling and hence high efficiency in imparting energy to the formation are achieved by virtue of the fact that the anvil is in contact with oil in the coupling device and this oil in effect is separated from the well fluid by a sleeve which is substantially acoustically transparent. It will be understood, however, that close coupling could be attained by removing the sleeve and permitting the well fluid to contact the anvil directly.

The seismic impulse that is thus transmitted to the liquid in the borehole enters the neighboring formations where some of the seismic impulse energy travels downwardly through the formations along the wall of the borehole to the pressure-responsive elements of the receivers 104 and 106. Electrical waves generated by the pressure-sensitive elements of the receivers are amplified in the receivers and transmitted to the surface, where their times of arrival are measured relative to the instant at which the seismic impulse is generated in the transmitter 102, all as more fully described in said copending patent application Serial No. 462,062. The relative times of arrival of a seismic impulse at the receivers is employed to determine the velocity of transmission in the neighboring formation. By obtaining such measurements at a series of depths in a well, an interval log of the interval velocity of the well as a function of depth is obtained.

When the hammer strikes the anvil it bounces from it slightly and then strikes it again at intervals of about  $\frac{1}{4}$  sec. Even when the distance between the hammer and the lower receiver 106 is as great as about 20 ft. and even more, the second impact does not occur until after the waves travelling through the formation have arrived at the lower receiver 106. Thus later impacts do not interfere with the desired observations. The use of such large distances becomes practical with the efficient source of this invention.

The coupling device 110 serves not only to couple the anvil 126 with the liquid in the well and with the surrounding formations, but it also serves to decouple the housing member in which the transmitter 102 is arranged from the other sections of the testing unit. The coupling device 112 decouples the spacer from the two receivers 104 and 106. In a similar way the coupling device 114 that is located between the two receivers 104 and 106 decouples the housing members in which the two receivers are mounted.

The housings of the transmitter 102, the receivers 104 and 106 and the spacers 103 and 105 are composed of steel or some other suitably strong and rigid material. Metals and other materials of that type are characterized by high sound velocities of the order of 15,000'/sec. The seismic wave velocities characterizing the formations that intersect the well vary over a wide range from about say 5,000'/sec. to about 20,000'/sec. For this reason, any vibrations imparted by the anvil to the housing of the transmitter would tend to travel rapidly to the housing of the spacer 103 and from it to the next adjacent receiver 104, and any vibrations entering the housing of the spacer 103, or housing of the upper receiver 104 or

the spacer 105, would tend to travel to the lower receiver 106 unless precautions are taken to prevent such transmission of vibrations. The arrival of such vibrations at the receivers would tend to interfere with or conceal the vibrations reaching the pressure-responsive elements of the receiver through the surrounding formations. For this reason the coupling devices 110 and 112 are in the form of vibration filters which attenuate and retard the transmission of vibrations from one housing member to another.

The velocity of transmission of vibrations through each coupling device is low, partly because of the fact that the metallic spring 310 is of helical configuration, thereby establishing a long path for the vibrations to travel at high speed from one housing member to another, and also by virtue of the fact that the velocity of sound through the sleeve 312 is low. Furthermore, the sleeve 312 itself, being in contact with the helical spring 310 which it encloses, tends to damp or attenuate any vibrations, particularly flexural vibrations, which are transmitted along the helical spring. Furthermore, even though the extension member 314 is composed of metal characterized by a high sound velocity, any vibrations that are transmitted along the extension member 314 are insulated from the housing member beneath it by virtue of the slidable mounting of the cylinder 320 in the lower connector 302 of the coupling device and also by virtue of the insulating effect of the rubber ring 321 on the periphery of the cylinder 320.

Furthermore, the coupling devices 110, 112 and 114 act as compliance elements that cooperate with the inertias of the spacers 103 and 105 and the inertias of the receivers 104 and 106 to form low-pass vibration filters, thereby highly attenuating the transmission of any high frequency components of waves downwardly along the length of the testing unit 100. The low-pass mechanical or vibration filter so formed has a cut-off frequency of between about 1 c.p.s. and about 50 c.p.s. As a result, over a range at least, this filter attenuates components at higher frequencies by larger and larger amounts as the frequency increases. This range extends to a point above the cut-off frequency of the high-pass characteristic of the receiver.

The pre-amplifiers 334 and 344 connected with the pressure-responsive elements themselves have high-pass characteristics, having a low frequency cut-off between about 400 c.p.s. and 1000 c.p.s. Since the particular pressure-responsive element responds uniformly over a wide frequency range, the receiver as a whole has a high frequency characteristic. In a particular case the cut-off frequency of this characteristic was set at about 600 c.p.s. At this frequency the response was only about 70% of the response at higher frequencies of about 2000 c.p.s. and higher. Below the low frequency cut-off limit the receiver attenuates at a rate of about 6 db./octave the low frequency components of waves that might otherwise be transmitted by the pressure-responsive elements to the surface, the attenuation increasing at a rate of 6 db./octave below about 600 c.p.s.

Thus the coupling devices act as vibration filter units which act alone to a certain extent to attenuate and retard the transmission of vibrations from one housing member of the testing unit to another over a wide range of the spectrum from very low frequencies of, say, 100 c.p.s. to very high frequencies of, say, 50,000 c.p.s. and more. At the same time they also cooperate with the inertias of various sections of the testing unit and with the pre-amplifiers to attenuate the transmission of components of relatively low frequency below about 600 c.p.s. present in vibrations detected by the pressure-responsive unit.

The compliance and inertia characteristics of the low-pass filters formed by the coupling devices 110, 112, and 114 and the various inertia members are established very

largely by the following specific factors or characteristics of the elements of the testing unit:

|                                                                   |        |                 |    |
|-------------------------------------------------------------------|--------|-----------------|----|
| Total mass above upper coupling device 110                        | pounds | 100             | 5  |
| Total mass below upper coupling device 110                        | do     | 300             |    |
| Total mass below intermediate coupling device 112                 | do     | 210             | 10 |
| Total mass below lower coupling device 114                        | do     | 70              |    |
| Stretch of upper coupling device 110 without rubber sleeve        | inches | 3               |    |
| Stretch of upper coupling device 110 with rubber sleeve           | do     | $\frac{9}{16}$  | 15 |
| Stretch of intermediate coupling device 112 without rubber sleeve | do     | $2\frac{3}{4}$  |    |
| Stretch of intermediate coupling device 112 with rubber sleeve    | do     | $1\frac{1}{16}$ | 20 |
| Stretch of lower coupling device 114 without rubber sleeve        | do     | $3\frac{1}{4}$  |    |
| Stretch of lower coupling device 114 with rubber sleeve           | do     | $\frac{7}{8}$   |    |

While the transmission characteristics of the low pass mechanical filter established by the values of the compliance of the couplers and the values of the masses given approximately above, are not determined by these values alone, but also by other factors including among others the lengths of the elements and the density of the fluid in which they are suspended and the diameter of the borehole in which the testing unit is suspended, nevertheless they do provide an index of the transmission characteristics of the low-pass filter formed by them at low frequencies where the compliance values and inertias may be lumped. In any event, the cut-off frequency of the low-pass filter so formed when the testing unit is actually in use should be very low and in any event no more than about  $\frac{1}{50}$  to about  $\frac{1}{40}$  of the cut-off frequency at the low frequency end of the high-pass characteristic of the receivers. Thus the cut-off frequency of the low-pass filter so formed is made less than about 50 c.p.s.

It must be borne in mind that the action of the vibration, or mechanical, filter so provided, when considering the compliance characteristics of the couplers as lumped elements, is quite different from the action of the couplers when considered merely as transmission lines along which energy, especially high frequency components thereof, is transmitted from one part of the testing unit to another. The effectiveness of the coupling device in the latter respect is determined not merely by the combined action of the coupler compliances and the masses of the associated elements, but also by the action of the couplers in transmitting sound therethrough along their length. When transmitting sound in this manner, the coupling device 110 attenuates the transmission of energy from the transmitter 102 to any of the parts below including the spacer 103 and the receivers 104 and 106 very largely by virtue of the fact that the cross-sectional area of the spring wire and the cross-sectional area of the rubber sleeve are very small compared with the cross-sectional area of the anvil. Furthermore, the transmission of energy from the transmitter to parts below it is retarded very largely because of the fact that the spring interferes with the direct transmission of radiation through the sleeve and very largely because of the fact that the pitch of the spring is set at such a value that the longitudinal speed of travel of sound through the spring in a direction parallel to the axis X—X of the coupler is low compared with the speed of transmission of sound through the surrounding formations, even though the speed of transmission along the helical length of the spring is very high. To a first approximation so long as the pitch of

the spring is low, the longitudinal speed of sound through the spring is given by the formula

$$V_x = \frac{V}{2\pi RN}$$

where:

$N$ =number of turns per inch

$R$ =radius of helix

$V$ =velocity of sound in the metal

forming the spring

$V_x$ =speed of travel of sound in the direction of the longitudinal axis X—X

In a specific embodiment of the invention, the number of turns per inch was approximately 2 and the radius was about 2", so that the longitudinal velocity was about 3,000 ft./sec., a speed substantially below the speed of sound in water even though the velocity of sound in the spring metal was about 15,000 ft./sec. In any event, the longitudinal velocity of sound along the length of the coupler is made less than the lowest seismic wave velocity to be detected, and in any event is preferably less than about 5,000 ft./sec., which is approximately the speed of sound in the liquid filling the well.

From the foregoing description, it is apparent that a well testing unit has been provided with an efficient transmitter and with effective insulation means for preventing direct transmission of interfering signals from the transmitter to a receiver through the well testing unit and thence to the surface both at low frequencies and at high frequencies.

Though the invention has been described with particular reference to the logging of the interval velocity of formations intercepted by a well, it may also be employed to log other seismic wave characteristics of the formations. For example, by periodically generating a seismic impulse and recording the impulse at one or more receivers, after transmission through the neighboring formations, measurements may be made of the amplitudes of waves received at one receiver or the ratio of amplitudes of waves received at two receivers. These data supply a measure of the attenuation characteristics of the formations. By measuring such intensities or ratios of intensities at various depths in a well, a well log of the seismic wave attenuation characteristics of the formations is obtained.

Likewise by noting the frequency characteristics of waves received at different depths in a well, a log of such characteristics may be obtained. In this connection, it is to be noted that even though the hammer strikes the anvil with the same strength at each depth and even though the seismic or acoustic pulse created in the anvil may be substantially the same, the frequency characteristics of the waves received by the receivers differ widely from one depth to another according to the characteristics of the neighboring formations. Logs of such frequency or attenuation characteristics for a series of wells may be employed to correlate formations in the wells.

Although only one specific embodiment of the invention has been illustrated and described, it is clear that the invention is not limited thereto but is capable of being embodied in many mechanical forms. Various changes which will now suggest themselves to those skilled in the art may be made in the material, form, details of construction and arrangement of the elements without departing from the principles of the invention. Reference is therefore made to the appended claims to ascertain the scope of the invention.

The invention claimed is:

1. In apparatus for generating seismic waves in a borehole in the earth:

an elongated tubular housing adapted to be lowered on a cable from the surface of the earth into the borehole, an anvil member mounted transversely of said hous-

ing, said anvil member being adapted to be coupled to liquid in the borehole,

an elongated hammer member movable longitudinally in said housing,

a spring normally urging said members together, and operating means for periodically drawing said hammer member away from said anvil member against the force of said spring and for periodically releasing said hammer member to permit said spring to force said hammer member to strike said anvil member rapidly,

whereby a seismic impulse is periodically transmitted into the liquid in the borehole, said operating means comprising

a pair of sprockets that are spaced apart longitudinally in said housing,

an endless chain looped over said sprockets,

a motor arranged within said housing, and

a speed-reducing train of gears interconnecting said motor and one of said sprockets for driving said chain continuously,

and wherein said hammer member is provided with a hook member movable lengthwise along one side of said chain,

said chain being provided with an outwardly extending cocking member for engaging said hook member as said cocking member passes near one of said sprockets and for releasing said hook member as said cocking member passes near the other of said sprockets,

said cocking member while engaged with said hook member drawing said hammer member away from said anvil member against the force of said spring,

said spring forcing said hammer member to strike said anvil member rapidly when said hook member is released.

2. In apparatus for generating seismic waves in a borehole in the earth:

an elongated tubular housing adapted to be lowered on a cable from the surface of the earth into the borehole, an anvil member mounted transversely of said housing, said anvil member being adapted to be coupled to liquid in the borehole,

an elongated hammer member movable longitudinally in said housing,

a spring normally urging said members together, and operating means for periodically drawing said hammer member away from said anvil member against the force of said spring and for periodically releasing said hammer member to permit said spring to force said hammer member to strike said anvil member rapidly,

whereby a seismic impulse is periodically transmitted into the liquid in the borehole, said operating means comprising

a pair of sprockets spaced apart longitudinally in said housing, an endless chain looped over said sprockets,

a motor arranged within said housing,

and a speed-reducing train of gears interconnecting said motor with one of said sprockets for driving said chain continuously,

and wherein said hammer member is provided with a hook member movable lengthwise along one side of said chain,

said chain being provided with a pair of uniformly spaced outwardly extending cocking members, each cocking member engaging said hook member as said each cocking member passes near one of said sprockets and for releasing said hook member as said each cocking member passes near the other of said sprockets,

said each cocking member while engaged with said hook member drawing said hammer member away from said anvil member against the force of said spring,

said spring forcing said hammer member to strike said anvil member rapidly when said hook member is released.

3. Apparatus for generating seismic waves in a borehole in the earth comprising:

an elongated tubular housing adapted to be lowered on a cable from the surface of the earth into the bore-

hole, an anvil member mounted at the bottom end of said housing,

said anvil member being adapted to be coupled to liquid in the borehole,

an elongated hammer member movable longitudinally in said housing above said anvil member,

a helical spring encircling said hammer member normally urging said hammer member toward said anvil member, and

operating means for periodically raising said hammer member away from said anvil member against the force of said spring and for periodically releasing said hammer member to permit said spring to force said hammer member to strike said anvil member rapidly,

said operating means including

a pair of sprockets that are spaced apart longitudinally in said housing, an endless chain looped over said sprockets,

a motor arranged at the upper end of said housing,

and a speed-reducing train of gears interconnecting said motor with the upper sprocket for driving said chain continuously,

said hammer member being provided with an integral hook member movable lengthwise along one side of said chain,

said chain being provided with an outwardly extending cocking member for engaging said hook member as said cocking member passes near the lower sprocket and for releasing said hook member as said cocking member passes near the upper sprocket,

said cocking member while engaged with said hook member raising said hammer member away from said anvil member against the force of said spring,

said spring forcing said hammer member to strike said anvil member rapidly when said hook member is released,

whereby a seismic impulse is periodically transmitted into the liquid in the borehole each time said hammer member strikes said anvil member.

4. In apparatus for determining the seismic wave transmission properties of formations intersected by a borehole in the earth:

an elongated testing unit adapted to be lowered on a cable from the surface of the earth into the borehole,

said testing unit including

a pair of elongated tubular housing members and an elongated tubular coupling device, connecting said housing members in longitudinally spaced apart positions,

said tubular coupling device comprising a helical spring and an elastic sleeve enclosing said spring, a body of liquid filling said tubular coupling device,

an anvil member mounted within one of said tubular housing members adjacent said coupling device and in contact with said body of liquid,

an elongated hammer member movable longitudinally in said one housing member,

a helical spring encircling said elongated hammer member normally urging and entirely filling said hammer member and said anvil member together,

means for drawing said hammer member away from said anvil member against the force of said spring and for releasing said hammer member to permit said spring to force said hammer member to strike said anvil member rapidly,

whereby a seismic impulse is transmitted into the liquid in the borehole when the hammer member strikes the anvil member,

and a seismic wave receiver arranged within the other of said tubular housing members for detecting seismic waves traveling in the surrounding formation.

5. In apparatus for determining the seismic wave transmission properties of formations intersected by a borehole in the earth:

an elongated testing unit adapted to be lowered on a

cable from the surface of the earth into the borehole, said testing unit including

a series of at least three elongated tubular housing members, an elongated tubular coupling device connected between successive tubular housing members in series and supporting said housing members in longitudinally spaced apart position,

each of said tubular coupling devices comprising a helical spring and an elastic sleeve member enclosing each said spring, the velocity of transmission of vibrations in said coupling device along the length thereof being less than about 5000 ft./sec.,

an anvil member mounted within one of said tubular housing members adjacent a coupling device, a body of liquid in said last-mentioned coupling device, said body of liquid being in contact with said anvil member,

an elongated hammer member movable longitudinally in said one housing member,

means for periodically causing said hammer member to strike said anvil member to cause a seismic impulse to be transmitted periodically into the liquid in the borehole,

and a seismic wave receiver arranged within each of the other of said tubular housing members for detecting seismic waves traveling in the surrounding formation.

6. In apparatus for determining the seismic wave transmission properties of formations intersected by a borehole in the earth:

an elongated testing unit adapted to be lowered on a cable from the surface of the earth into a borehole, said testing unit including

a series of at least three elongated tubular housing members, an elongated tubular coupling device connected between successive tubular housing members in the series and supporting said housing members in longitudinally spaced apart position,

each of said tubular coupling devices comprising a helical spring and an elastic sleeve member enclosing each said spring, the velocity of transmission of vibrations in said coupling device along the length thereof being less than about 5000 ft./sec.,

an anvil member mounted within one of said tubular housing members adjacent a coupling device, a body of liquid in said last-mentioned coupling device, said body of liquid being in contact with said anvil member,

an elongated hammer member movable longitudinally in said one housing member,

a helical spring encircling said elongated hammer member normally urging said hammer member and said anvil member together,

means for periodically causing said hammer member to strike said anvil member to cause seismic impulses to be transmitted periodically into the liquid in the borehole,

a seismic wave receiver arranged within each of the other of said tubular housing members for detecting seismic waves traveling in the surrounding formation,

and electrical conductors connected to each of said receivers and leading upwardly through said housing members for transmitting signals produced by said receivers to the surface of the earth.

7. In apparatus for determining the seismic wave transmission properties of formations intersected by a borehole in the earth:

an elongated testing unit adapted to be lowered on a cable from the surface of the earth into the borehole, said testing unit including

a pair of elongated tubular housing members, an elongated tubular coupling device connected between said housing members,

said tubular coupling device comprising a helical spring and an elastic sleeve enclosing said spring,

a seismic wave generator arranged in one of said tubular housing members, said seismic wave generator being adapted to transmit a seismic wave impulse into a surrounding formation,

a seismic wave receiver arranged within the other of said tubular housing members for detecting seismic waves traveling in the surrounding formation, the time of transmission of vibrations from said anvil member to said seismic wave receiver through said coupling device being greater than the time of transmission of waves from said anvil member to said seismic wave receiver through the formation surrounding the borehole,

and electrical conductors connected to said receiver and to said seismic wave generator leading upwardly through said housing members for transmitting signals produced by said receiver to the surface of the earth.

8. In apparatus for determining the seismic wave transmission properties of formations intersected by a borehole in the earth:

an elongated testing unit adapted to be lowered on a cable from the surface of the earth into the borehole, said testing unit including

a series of at least three elongated tubular housing members, an elongated tubular coupling device connected between successive tubular housing members in the series and supporting said housing members in longitudinally spaced apart position,

each of said tubular coupling devices comprising a helical spring and an elastic sleeve member enclosing each said spring,

a seismic wave generator arranged in one of said tubular housing members, said seismic wave generator being adapted to transmit a seismic wave impulse into a surrounding formation,

a seismic wave receiver arranged within each of the other of said tubular housing members for detecting seismic waves traveling in the surrounding formation, the time of transmission of vibrations from said anvil member to said seismic wave receiver through said coupling device being greater than the time of transmission of waves from said anvil member to said seismic wave receiver through the formation surrounding the borehole,

and electrical conductors connected to said receivers and to said seismic wave generator leading upwardly through said coupling devices and said housing members for transmitting signals produced by said receivers to the surface of the earth.

9. In apparatus for generating seismic waves in a borehole in the earth: a housing adapted to be lowered on a cable from the surface into the borehole, a pair of relatively movable members arranged in said housing, a spring normally urging said members together, means operatively coupled to at least one of said members for periodically slowly drawing said members apart against the force of said spring and for releasing said member to permit said spring to force said members together rapidly, whereby a seismic impulse is periodically transmitted into the formations surrounding the borehole, and means mounted within said housing adjacent the path of movement of said members and responsive to movement of said members toward one another for providing an electrical signal indicative of the time of said seismic impulse generation.

10. The apparatus of claim 9 wherein said housing is of elongated tubular configuration, said pair of relatively movable members comprising a first anvil member extending transversely of said tubular housing, and a second elongated hammer member extending longitudinally in said housing, said spring comprising a strong helical compression spring encircling said elongated hammer member throughout the larger portion of the length thereof.

11. The apparatus of claim 9 wherein said means for providing said electrical signal comprises an electrical switch mounted on one of said relatively movable members and electrically connected to equipment located at the surface of the earth, said switch being adapted to assume a first state of actuation for producing a timing signal at said earth surface located equipment when said relatively movable members move into engagement with

one another, and being adapted to assume a non-signal producing opposite state of actuation when said relatively movable members are remote from one another.

12. The apparatus of claim 9 wherein said means for drawing said members apart includes an electric motor having a driving rotary member located wherein said housing, means within said housing operatively engageable with at least one of said movable members and including a driven rotary member adapted to draw said members apart against the force of said spring, and a speed reducing mechanism connected between said driving member and said driven member for rotating the latter at a lower speed than the former and at an increased torque.

13. In apparatus for determining the seismic wave transmission properties of formations intersected by a borehole in the earth: an elongated testing unit adapted to be lowered on a cable from the surface of the earth into the borehole, said testing unit including a series of at least three elongated tubular housing members, an elongated coupling device connected between successive tubular housing members in the series and supporting said housing members in longitudinally spaced apart position, each of said coupling devices including filter means comprising a helical spring attached at its opposing ends to an adjacent pair of said spaced housing members for attenuating and retarding the transmission of vibrations from one to the other of said adjacent pair of housing members, a seismic wave generator arranged in one of said tubular housing members, said seismic wave generator being adapted to transmit a seismic wave impulse into a surrounding formation, and a seismic wave receiver arranged within each of the other said tubular housing members for detecting seismic waves traveling in the surrounding formation, the time of transmission of vibrations from said anvil member to said seismic wave receiver through said coupling device being greater than the time of transmission of waves from said anvil member to said seismic wave receiver through the formation surrounding the borehole.

14. In apparatus for generating and receiving seismic waves in a borehole in the earth: a pair of spaced elon-

gated tubular housings adapted to be lowered in spaced substantially coaxial relation to one another on a cable from the surface of the earth into the borehole, a rod-shaped anvil member mounted in one of said tubular housings, said anvil member being adapted to emit vibratory energy into liquid in said borehole when said anvil is struck, a hammer member located above said anvil member and being movable longitudinally in said one housing, a first spring means operatively associated with said hammer member for normally urging said hammer member toward said anvil member, means operatively associated with said hammer and anvil members for raising said hammer member against the force of said spring means and for releasing said hammer member to permit said spring means to force said hammer member to strike said anvil member thereby to generate said seismic wave, a seismic wave receiver in the other of said tubular housings, and means mechanically connecting said housings to one another for simultaneously retarding the passage of vibratory energy between said housings comprising a second spring having its opposing ends spaced from one another and connected respectively to said pair of housings adjacent the spaced facing ends of said housings.

#### References Cited in the file of this patent

##### UNITED STATES PATENTS

|           |              |               |
|-----------|--------------|---------------|
| 1,883,433 | Williams     | Oct. 18, 1932 |
| 2,156,052 | Cooper       | Apr. 25, 1939 |
| 2,233,992 | Wyckoff      | Mar. 4, 1941  |
| 2,265,768 | Athy et al.  | Dec. 9, 1941  |
| 2,681,442 | Schurman     | June 15, 1954 |
| 2,694,461 | Martin       | Nov. 16, 1954 |
| 2,708,485 | Vogel        | May 17, 1955  |
| 2,712,124 | Ording       | June 28, 1955 |
| 2,722,282 | McDonald     | Nov. 1, 1955  |
| 2,728,902 | White et al. | Dec. 27, 1955 |
| 2,788,510 | Howes        | Apr. 9, 1957  |
| 2,794,512 | Martin       | June 4, 1957  |

##### FOREIGN PATENTS

|         |               |               |
|---------|---------------|---------------|
| 174,354 | Great Britain | July 19, 1923 |
|---------|---------------|---------------|