

Jan. 16, 1962

D. L. COURSEN
SURFACE WAVE GENERATOR

3,016,831

Filed Oct. 2, 1958

4 Sheets-Sheet 1

Fig. 1

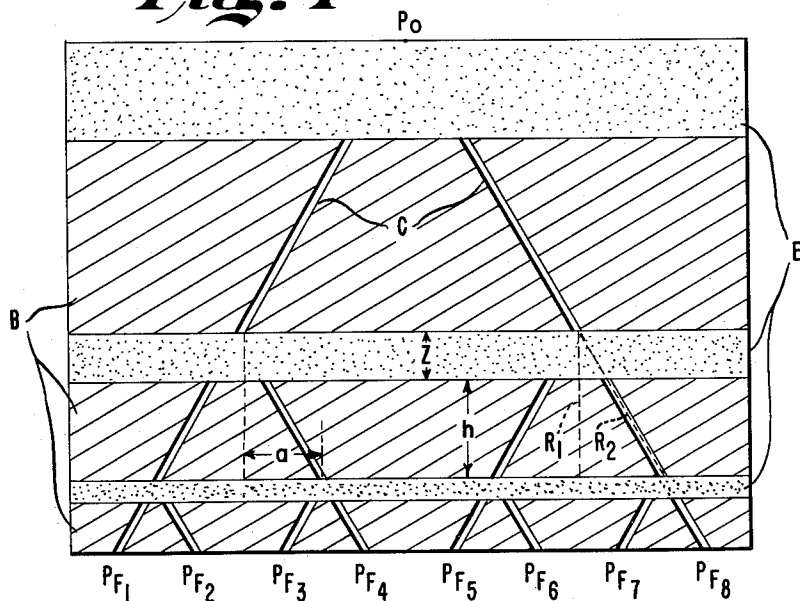
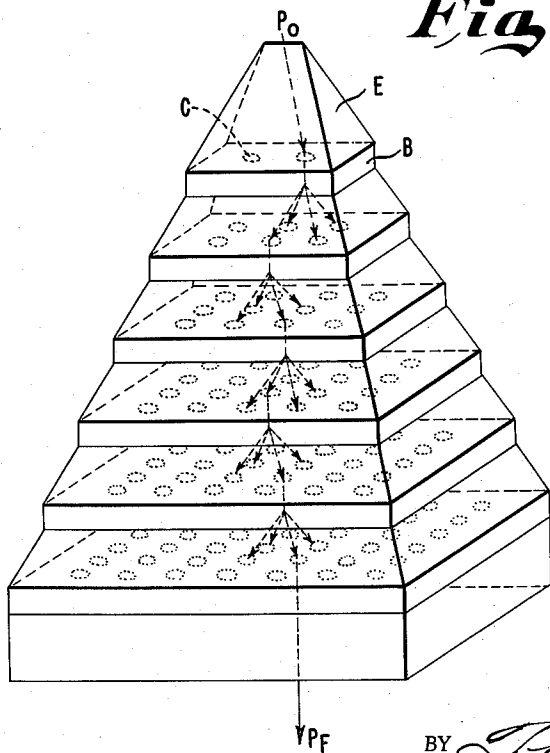


Fig. 2



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Fig. 3

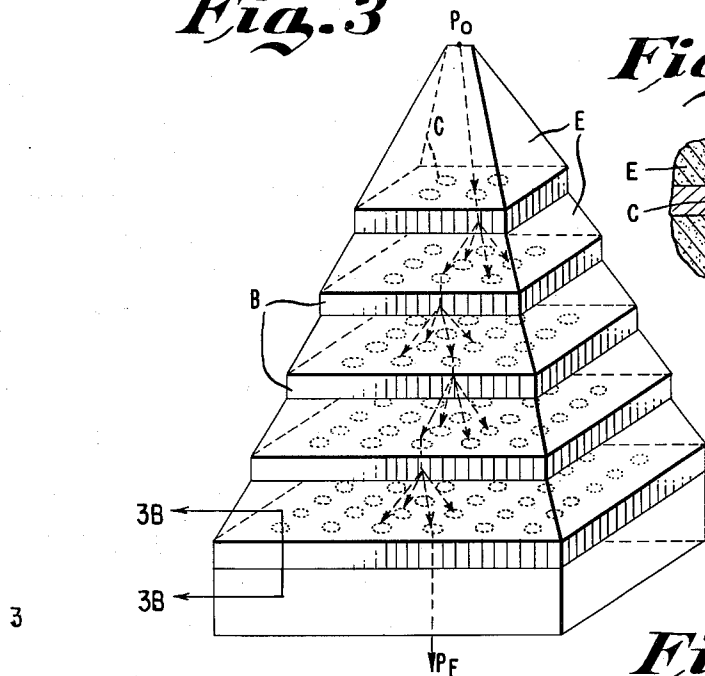


Fig. 3B

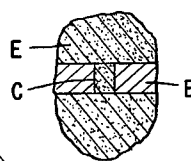
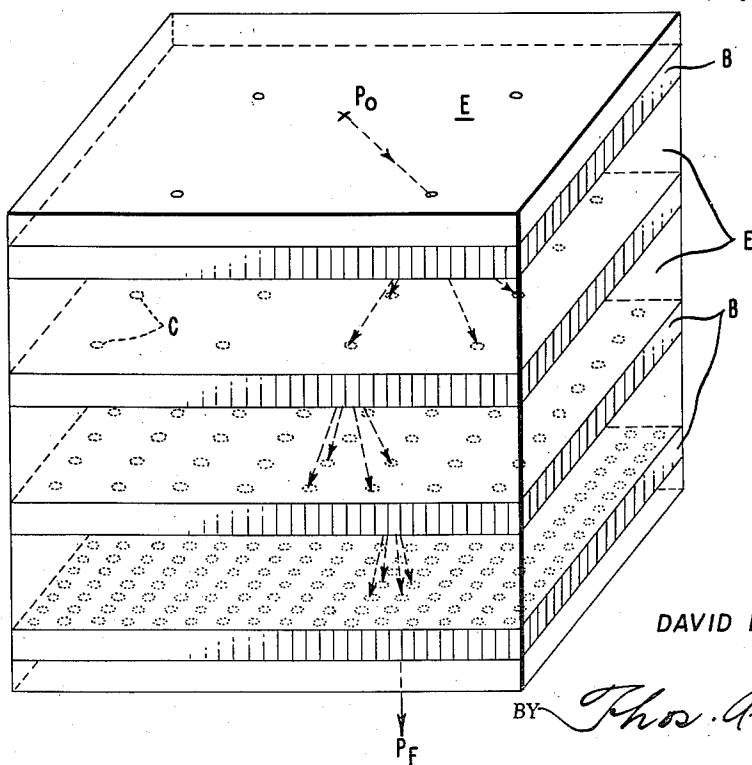


Fig. 4



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Fig. 5

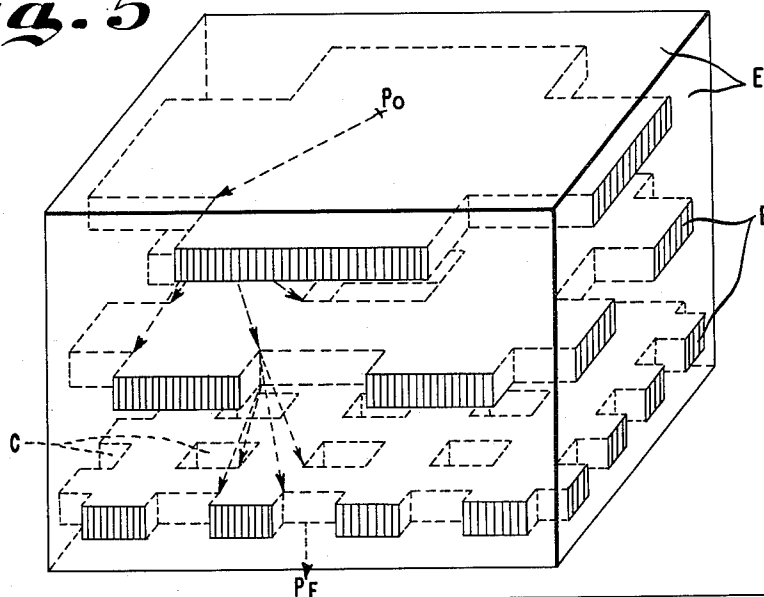
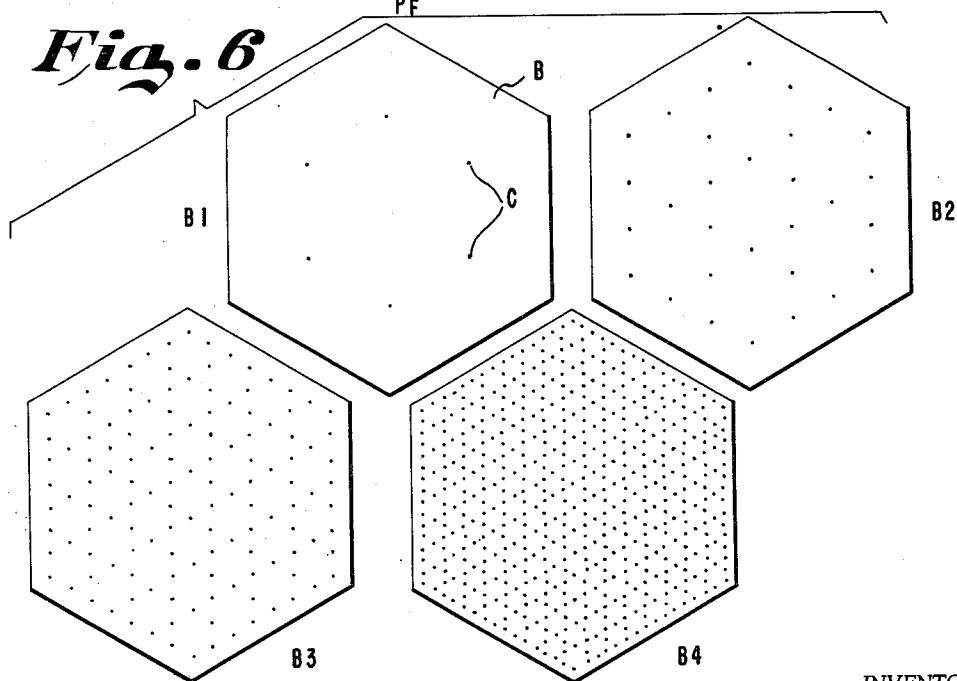


Fig. 6



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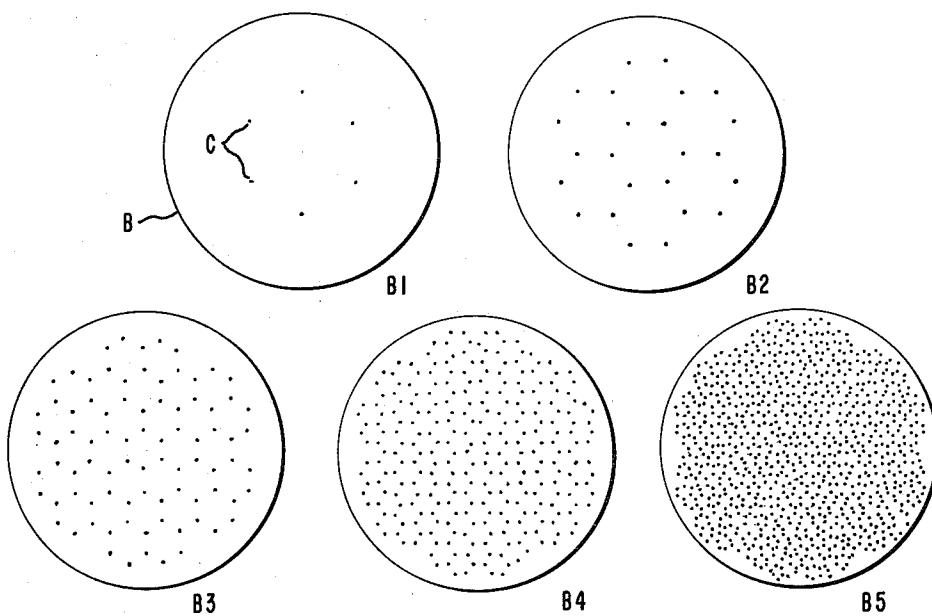
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Fig. 7



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3,016,831

SURFACE WAVE GENERATOR

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3 Claims. (Cl. 102-22)

The present invention relates to a novel high-explosive device wherein the natural detonation front is distorted. More particularly, the present invention relates to a surface-wave generator, i.e., a high-explosive device wherein a detonation front generated at one point is made to arrive simultaneously at a plurality of points on a desired surface.

When a homogeneous mass of a high explosive is initiated at one point, the resultant detonation front proceeds outwardly from the point of initiation at uniform velocity in all directions. For example, in the case in which a spherical charge of a high explosive is initiated at its center, the detonation front travels uniformly through the charge as an expanding sphere, the front eventually arriving simultaneously at all points on the surface of the charge. When, however, the spherical charge is not initiated at its center but at an eccentric point such as a point near its surface, the detonation front in this second case initially constitutes an expanding sphere until the portion of the boundary nearest the point of initiation is reached. Thereafter, the front travels through the remainder of the charge as an expanding segment of a sphere, the radius of curvature of the segment at any given point in the charge being determined by the distance from the initiation point. In the third case, a non-spherical homogeneous mass of explosive, e.g. a pyramid, centrally or eccentrically initiated, the detonation front proceeds in the same manner as in the eccentrically initiated spherical charge. It is obvious that in either case 2 or case 3 the detonation front, because of its natural curvature, does not arrive simultaneously at all points on the surface of the charge but arrives at various times depending upon the distance between each finish point and the starting, or initiation, point.

In many applications of explosives besides blasting, it is desirable to employ an explosive charge wherein the detonation front arrives simultaneously at a plurality of predetermined points on one or more surfaces of the charge. For example, U.S. Patent 2,604,042 (Cook, J. H., to Imperial Chemical Industries, Ltd., July 22, 1952) describes a method whereby a metal surface is embossed by means of a plane detonation front, i.e. a detonation front which is distorted to arrive simultaneously at a plurality of points on a surface. The explosive charge used is a composite charge consisting of several different explosives, each having a different detonation velocity. The form of the charge is such that not only a great deal of care must be taken in correlating the different detonation velocities but also a large quantity of explosive material must be incorporated into the charge. This large amount of explosives increases the cost of the unit and, moreover, frequently results in the destruction of the adjacent metal surface due to the brisance of the explosive which is present in such large quantities. Obviously, the provision of a charge capable of producing the desired distortion of the detonation front and yet consisting of an inherently smaller quantity of explosive material is of great value in this application. Moreover, the use of such a surface-wave generator is exceedingly valuable in basic investigations of explosive phenomena. For example, in a fundamental study of the subjection of objects such as metal plates to

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explosive superpressures, i.e. the exceedingly high pressures of short duration generated by a high explosive, a determination of the effect of a plane detonation front is of interest. A prerequisite of such an investigation of course is the availability of an explosive charge which not only will generate the plane detonation front but also not destroy the object subjected to the superpressures.

Accordingly, an object of the present invention is the provision of an explosive device wherein the detonation front generated at one point is directed to arrive simultaneously at a plurality of points on a surface. Another object of the present invention is the provision of a surface-wave generator in which only one explosive composition is required. A still further object of the present invention is the provision of a surface-wave generator causing a minimum of damage to adjacent objects.

I have found that the foregoing objects may be achieved when I provide a surface-wave generator comprising a plurality of layers of a cap-sensitive high-explosive in conormal relationship, the thickness of each of the explosive layers being such as to exceed the minimum thickness for support of the detonation, each of the explosive layers being separated one from another by a barrier plate provided with an array of detonation-transmitting channels, the array of the channels in successive plates being such that the axis of each channel in a given plate is equidistant from the axis of each of a plurality of channels in the immediately following plate. In accordance with the present invention, the thickness, h , of a given barrier plate and the thickness, z of the explosive layer superincumbent upon the given barrier plate are so interrelated with the wall-to-wall lateral displacement, a , of the base of a channel in the channel in the given barrier plate and the base of the nearest channel in the immediately preceding plate that the ratio of the lateral displacement, a , to the barrier-plate thickness, h , is at most

$$3 \left[11 + 2 \left(\frac{z}{h} \right) \right]^{1/2}$$

In order to describe more completely the nature of the present invention, reference now is made to the accompanying drawings, in which:

FIGURE 1 is a front view in cross-section of a surface-wave generator constructed in accordance with the principles of the present invention, the unit being depicted in a manner such as to facilitate an understanding of the theoretical considerations involved in the invention,

FIGURES 2-7 represent various embodiments of the unit of the present invention, and

FIGURE 3b is a section taken along line 3b-3b of FIGURE 3.

Referring now to the figures, especially to FIGURE 1, in more detail, in all drawings, P_0 is the starting, or initiation, point; E is the explosive layer; B is the barrier plate; C is the detonation-transmitting channel in barrier plate B; and P_F is a finish point on the surface of the unit.

The explosive units of the present application are based upon the following principles: (1) a homogeneous explosive mass normally detonates at uniform velocity in all directions and (2) the detonation generates in adjacent nonexplosive materials a shock which propagates through the material at a velocity which may be distinct from that of the detonation velocity and is capable of initiating detonation in an adjacent mass of explosive. Considering first a solid homogeneous explosive block of the form shown in FIGURE 1, the detonation front initiated at point P_0 and moving at uniform velocity will proceed through the block in the main as an expanding segment of a sphere. Thus, the front will arrive first

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at the finish points, P_{F4} and P_{F5} , which are nearest to initiation point P_0 and last at the furthest points P_{F1} and P_{F8} .

Now, if layers of a material in which the shock velocity is equal to the detonation velocity of the explosive are interposed between layers of explosive, i.e. if the barrier plates B of FIGURE 1 were composed of such a material, the time interval required for the shock to travel through a plate of this material would equal the time required for a detonation front to travel an equivalent distance through explosive. Thus, in this case the detonation front would again arrive at P_{F4} and P_{F5} first and P_{F1} and P_{F8} last.

In the case in which the barrier plates B comprise a material having a shock velocity lower than the detonation velocity of the explosive, the time interval required for the shock to travel through a plate of this material would exceed that time required for the detonation to travel an equivalent distance through explosive. Thus, considering two layers of explosive separated by a plate of low shock velocity material, the time interval between the initiation of the detonation in the upper most layer and the completion of the detonation process in lowermost layer would be greater than that resulting when the two layers are separated by an explosive layer equal in thickness to the barrier plate.

Now, if channels C are provided in the low shock velocity barrier plates B, through which channels the detonation-propagating stimulus is transmitted at a rate higher than the velocity of the initiation-inducing shock traveling through the plate, those portions of the explosive layer below the channels will be initiated first and the rest of the layer later or not at all if the shock has decayed to the level at which it is incapable of effecting initiation.

I have found that by alternating explosive layers and barrier plates having a shock velocity lower than the detonation velocity and provided with detonation-transmitting channels in the proper array, an explosive unit may be constructed in which the natural detonation front is distorted to arrive simultaneously at a plurality of points on its base. The channels are such that the vertical component of the velocity of the agent which transmits the detonation therethrough exceeds the velocity of the shock passing through the remainder of the barrier plate. Thus, the detonation-transmitting channels C in barrier plate B may be filled with an explosive E, as is shown in FIGURE 3b, or they may be air filled, the detonation passing over air gaps of proper size without dying out and more rapidly than the shock proceeds through the barrier material. The channels in the plates define a plurality of paths between the starting point, P_0 , and the finish points, P_F , along which the detonation-transmitting stimulus travels at a uniform rate higher than that of the shock passing through the barrier plates. Although a multiplicity of paths exist, for every finish point there is a shortest path from the starting point. To effect the desired simultaneous arrival of the detonation front at a plurality of finish points, the time required for the detonation front to travel through all the shortest starting point-finish point paths defined by the channels must be equal. Thus, since the detonation is traveling at uniform rate along all the paths, all shortest paths must be equal in length. To provide the equilength shortest paths, the channels are so arrayed in successive plates that the axis of each channel in a given barrier plate is equidistant from the axis of each of a plurality of channels in the immediately following plate.

FIGURE 2 illustrates one unit constructed in accordance with the aforespecified requirements. In this unit, two channels C are provided in the uppermost barrier plate B and the channels in the next plate are disposed in square array below the upper channels. In this unit as shown, the detonation front travels through 42 channels in the lowermost plate and thus arrives simultaneously at 42 finish points on the base of the unit. A mathematical

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expression, Equation 1, may be set up relating the number of channels C in a given plate B for this unit:

$$M=N(N+1) \quad (\text{Equation 1})$$

5 M being the number of channels and N being the barrier plate number.

FIGURE 3 shows another embodiment of the surface-wave generator of the present invention. In the depicted units of this embodiment, the front arrives simultaneously at 36 finish points on the base. The unit shown has five barrier plates and 4 channels in the uppermost plate, the equation relating the number of channels in a plate to the plate number being:

$$M=(N+1)^2 \quad (\text{Equation 2})$$

15 In FIGURE 4 showing another embodiment of the present invention, the top plate of the unit again is provided with four channels, the number of channels in a given plate being related to the plate number in accordance with Equation 3:

$$M=2^{2N} \quad (\text{Equation 3})$$

A unit such as this having 4 barrier plates provides for simultaneous initiation at 256 points on its base.

25 The unit of FIGURE 5 is a slight modification of that shown in FIGURE 4, the four channels in the uppermost plate being formed by cutting away the corners of the plate. In the lower plates, the channels are formed by cutting away the four corners of each plate and also cutting away, as shown, portions along the edges of the plate, which portions are defined by adjacent pairs of channels of the FIGURE 4 embodiment. Channels are provided symmetrically in the interior portions of the lower plates, which portions correspond to squares delineated in the plate by the FIGURE 4 channels. Each concave corner of the cut-away portions acts as a detonation-transmitting channel. In the plates in the FIGURE 5 embodiment, Equation 3 also governs the relationship between number of channels in a given plate and plate number.

40 In FIGURE 6 is shown a series of hexagonal barrier plates, B_1 - B_4 , suitable for use in another embodiment of the instant surface-wave generator, only the plan view of the plates being shown for simplicity. The uppermost plate is provided with six channels in hexagonal array, the flats of all hexagons delineated by the channels in the plates being parallel to an edge of the plate. The relation governing the number of channels in a given plate with respect to plate number is set forth in Equation 4:

$$M=[3(2^{N-1})][3(2^{N-1})-1] \quad (\text{Equation 4})$$

Inasmuch as the fourth, and last, barrier plate shown for the FIGURE 6 embodiment has 552 channels, the total number of finish points at which the detonation front arrives simultaneously equals 552.

55 Again for simplicity's sake, the circular barrier plates of the FIGURE 7 embodiment rather than the complete unit are represented. In this embodiment as shown, five plates are used. In B_1 , the uppermost of the barrier plates, 6 channels are provided in hexagonal array. The channels in the subsequent plates are also in hexagonal array, the channels in the subsequent plates being so positioned that the hexagons thus delineated are rotated 30° on their axes with respect to the hexagons in the previous plate. The mathematical expression relating the number of channels in a given plate to the plate number is:

$$M=6\left[3^{N-1}+\sum_{m=0}^{N-2}2^m3^{(N-2-m)}\right] \quad (\text{Equation 5})$$

70 N being greater than 1 and M equalling 6 when N equals 1. Since B_5 , the lowermost barrier plate shown, thus contains 876 channels, there will be 876 simultaneous finish points in the units as constructed.

75 Regardless of the exact configuration of the surface-

wave generator of the present invention, several basic requirements must be fulfilled in order that the detonation front will arrive simultaneously at a number of finish points on its base. First, the unit must be constructed of conormal layers of a cap-sensitive high explosive alternated with barrier plates, and the explosive layers must be of sufficient thickness for support of the detonation. The barrier plates must be provided with an array of detonation-transmitting channels which are so disposed in successive plates that the axis of each channel in a given plate is equidistant from the axis of each of a plurality of channels in the immediately following plate. Lastly, referring again to FIGURE 1, the thickness, h , of a given barrier plate and the thickness, z , of an explosive layer superincumbent upon the given plate must be so interrelated with the wall-to-wall lateral displacement, a , of the base of a channel in the given barrier plate and the base of the nearest channel in the immediately preceding plate that the ratio of the lateral displacement, a , to the barrier-plate thickness, h , is at most

$$3\left[11+2\left(\frac{Z}{h}\right)\right]^{1/2}$$

The exact cap-sensitive high explosive used in the units of the present invention is not critical. Suitable explosives include such crystalline compounds as RDX, HMX (cyclotetramethylenetetranitramine), PETN, lead azide, nitromannite, and the like, which may be prepackaged in layer-like thin-walled containers for incorporation in the unit. However, for ease of handling and ease of thickness control, the use of self-supporting, coherent, sheet-like explosive layers is preferred. Such self-supporting layers may be formed by admixing one of the afore-named crystalline compounds with a suitable binding agent, or such gelatinous masses as blasting gelatin formed from nitroglycerin, which normally is a liquid, may be used. Preparation of the units at times may be facilitated by use of those binary castable mixtures such as cyclotol (a TNT-RDX mixture), pentolite (a TNT-PETN mixture), and tetrytol (a tetryl-TNT mixture).

The thickness of the explosive layer must exceed the minimum thickness required for support of detonation. Since the minimum thickness is dependent upon the specific explosive used, no exact value may be specified for the required minimum thickness of the explosive layer. However, I have found that for a very sensitive explosive the minimum thickness for support of the detonation is 0.2 millimeter. Therefore, on a practical basis, the lower limit on explosive layer thickness may be stated to be at least 0.2 millimeter.

The specific material used as the barrier plate is not critical, so long as its shock velocity is lower than the detonation velocity of the specific explosive used. For example, steel having a shock velocity of 5000 meters per second would be unsuitable when the explosive detonates at a velocity of 3000 meters per second but would be suitable with an explosive detonating at a rate of 6000-7000 meters per second. Suitable barrier materials include cardboard, felt, cork, wood, foamed aluminum, among many others. Because of their low shock velocity, such substances as foamed aluminum are preferred. However, various other factors including economics, availability, ease of handling, and the like will also be considered in the selection of the exact barrier plate material used.

In order to effect the desired functioning of the units, the barrier plates must be provided with detonation-transmitting channels in proper array as aforedefined. These channels may be disposed at right angles to the horizontal surface of the barrier plate or they may be disposed at oblique angles to this surface. The detonation is transmitted through these channels at a rate greater than that at which the shock is transmitted through the barrier plate itself. Thus, the channels may merely constitute air gaps between adjacent layers of explosive or they may be filled with explosive and thus constitute explosive

trains between adjacent layers of explosive. When air-filled channels are used, a layer of thin metal foil, e.g. of lead, may be inserted between the explosive layer and the barrier plate, the foil, which produces metal particles, acting to enhance propagation across the air gap.

Regardless of whether the channels constitute air gaps or explosive trains, the cross-sectional area of the channel must be at least 0.04 square millimeter. When the channels are explosive filled, their length is immaterial. On the other hand, when the channels constitute air gaps, their maximum length should not exceed that distance across which the detonation is sustained. Inasmuch as this maximum distance is a direct function of the specific explosive used, no exact value may be set for the maximum length of air gap. In correlation with this consideration, the thickness of the barrier plate also is a factor, since the thickness is directly related to the channel length. The barrier plate thickness, h , as afore-indicated, is interrelated with both the thickness of the explosive layer, z , and the previously defined lateral displacement of channels in adjacent layers in accordance with the equation:

$$\frac{a}{h} \leq 3\left[11+2\left(\frac{Z}{h}\right)\right]^{1/2}$$

Thus, the thickness of the barrier is governed not only by the thickness of the explosive layer but also the extent of the lateral displacement of channels. Therefore, no exact value can be set for the barrier thickness. As has been indicated, however, the length of the air-filled channels must not exceed that distance across which the detonation is sustained. Thus, in the case of this type of channel the thickness of the barrier plate must not exceed that value which will provide for the maximum length air gap, whether the channels be at right or oblique angles to the surface of the barrier plate. Naturally, there is no limitation on the maximum barrier thickness when the channels are filled with explosive aside from that dictated by the previous equation. However, inasmuch as the use of excessively thick barriers generally serves no useful purpose while increasing the over-all cost and size of the unit, the limitation on maximum barrier thickness imposed by the use of air gaps will serve for all practical purposes when the explosive-filled channels are used.

In this connection, it must be stated that definite principles serve to determine the mathematical expression derived to interrelate thickness, z , of the explosive layer, which thickness on a practical basis will always be at least 0.2 millimeter, thickness, h , of the barrier plate below the given explosive layer, and the positioning of the channels in this plate as defined by a , the wall-to-wall lateral displacement of the base of a channel in this plate and the base of the nearest channel in the immediately preceding plate. Referring again to FIGURE 1 and assuming the limiting case that the time required for the shock to travel directly through the barrier along R_1 equals the time required for the detonation to travel along the longer path, R_2 , defined by the detonation-transmitting channel, the following expression may be set up:

$$\frac{Z}{D} + \frac{h}{S} \geq \frac{[(Z+h)^2 + a^2]^{1/2}}{D}$$

wherein Z , h , and a are as aforedefined and illustrated in FIGURE 1, D is the detonation velocity of the explosive, and S is the shock velocity in the barrier. This expression may be rearranged to give the condition:

$$\frac{a}{h} \leq \left[\left(\frac{D^2}{S^2} - 1 \right) + 2 \left(\frac{D}{S} - 1 \right) \left(\frac{Z}{h} \right) \right]^{1/2}$$

For a dense, porous barrier material, which materials have very low shock velocities, D/S can be as large as 10. Thus, it may be stated generally that

$$\frac{D}{S} \leq 10$$

the ratio decreasing with less dense and porous materials and lower velocity explosive. Consequently,

$$\frac{a}{h} \leq 3 \left[11 + 2 \left(\frac{Z}{h} \right) \right]^{1/2}$$

In the addition to the six exemplified configurations of the surface-wave generator of the present invention, many other configurations and/or variations on the exemplified units may be constructed in accordance with the previously specified requirements. The exact configuration used will be selected on the basis of the application to which it is put, such factors as the number of finish points desired on the base of the unit, the over-all dimensions of the unit, economics, and the like. As has been shown, the number of finish points varies with the particular configuration used and with the number of barrier plates disposed in the given configuration. The following table serves to illustrate these points.

Table

Barrier Plate No.	Figure 2 Unit (Eq. 1) ¹		Figure 3 Unit (Eq. 2) ¹		Figure 4 Unit (Eq. 3) ¹		Figure 5 Unit (Eq. 3) ¹		Figure 6 Unit (Eq. 4) ¹		Figure 7 Unit (Eq. 5) ¹	
	No. of Chan- nels	No. of Finish Pts.	No. of Chan- nels	No. of Finish Pts.	No. of Chan- nels	No. of Finish Pts.	No. of Chan- nels	No. of Finish Pts.	No. of Chan- nels	No. of Finish Pts.	No. of Chan- nels	No. of Finish Pts.
1.-----	2	2	4	4	4	4	4	4	6	6	6	6
2.-----	6	6	9	9	16	16	16	16	30	30	24	24
3.-----	12	12	16	16	64	64	64	64	132	132	84	84
4.-----	20	20	25	25	256	256	256	256	552	552	276	276
5.-----	30	30	36	36	1,024	1,024	1,024	1,024	2,256	2,256	876	876
6.-----	42	42	49	49	4,096	4,096	4,096	4,096	9,120	9,120	2,724	2,724

¹ Equation numbers refer to the previously specified equations relating the number of channels in a given plate to the plate number in a given embodiment.

As clearly shown in this table, certain embodiments of the surface-wave generator of the present invention, for example the FIGURES 2 and 3 units, inherently give fewer finish points per given plate number than do others, for example, the FIGURE 6 unit. Moreover, the number of finish points in a given unit increases with increase in the number of plates employed in the unit. If the application in which the unit is to be used requires the latter to provide only a few finish points, e.g. 12, a FIGURE 2 unit constructed to contain only 3 plates would be suitable. On the other hand, when a very great number of finish points are required for the application, the FIGURE 6 unit having 6 or more plates would be used.

In general, the units will be so designed that the initial barrier plate contains more than one channel. When one channel is used in the uppermost plate, it acts solely as an initiation point. At times, such construction, however, may be desirable. Usually, also, at least two plates will be provided in each unit, one plate seldom providing sufficient finish points for the application and the use of at least two plates insuring the proper timing of the unit.

Although for ease of description due to simplicity, only those units having explosive layers and barrier plates which are coplanar have been illustrated, the invention is not restricted to units having such coplanar elements, the only requirement being that the explosive layers and barrier plates be disposed in conormal relationship. Thus, for example, a unit may be constructed in which the explosive layers and barrier plates constitute segments of a sphere disposed in conormal relationship. In the resulting unit, the finish points, naturally, will be on a curved rather than planar surface. A number of such segmental units may be assembled to provide a spherical unit giving a plurality of finish points on the interior surface of the sphere. Of course, a number of any of the exemplified configurations may also be assembled. This procedure may be used, for example, when the number of finish points desired is large but a unit limited in height is needed, the increase in plates required to increase the number of finish points in a given unit obviously increasing also the height of the unit.

The over-all dimensions of the unit are not critical, 75

this feature being dependent upon the application to which the unit will be put. A unit constructed in accordance with the requirements of the invention may be so built to provide only a few, widely spaced finish points on a given surface area by spacing the channels far apart. By using closely spaced channels, the number of finish points on a given area may be greatly increased. As afore-stated, the height of the unit is regulated in the main by the number of plates employed. The bottom surface of the unit may consist of an explosive layer or a barrier plate depending upon the application to which the unit is put. Furthermore, the use of a one-channel barrier plate as the uppermost surface is also very feasible, the channel acting, in part, as a supporting means for the initiator, for example an electric blasting cap, or the cap may be abutted against an uppermost explosive layer.

As has been indicated, a number of methods are feasible for the preparation of the units, the exact explosive

used generally dictating the preparative procedure. If use of a castable explosive is desired in a unit having explosive-filled channels, the barrier plates provided with channels in the proper array may be supported at the desired spacing within a mold and heated, and then the explosive melt will be poured into the mold. After cooling, the unit is removed from the mold. The explosive melt may also be cast into flat slabs, which are then alternated with the barrier plates, for example if the use of air gaps for the detonation-transmitting channels is desired. When the self-supporting layers of explosive are used, they are merely alternated with the barrier plates, the channels being filled with explosive or not as desired. Although for ease of manufacture it may be desirable to use only one explosive composition in the unit, several different compositions may also be employed if the obtaining of special results is required. For example, the lowermost layer may comprise a more highly brisant explosive than the explosive of the previous layers. The explosive in a given layer, however, must detonate at uniform velocity.

The invention has been described in detail in the foregoing. However, it will be apparent to those skilled in the art that many variations are possible without departure from the scope of the invention. I intend, therefore, to be limited only by the following claims.

I claim:

1. A surface-wave generator wherein the natural detonation front is distorted to arrive simultaneously at a plurality of points on its surface which comprises a plurality of parallel layers of cap-sensitive, high explosive in conormal relationship to one another, the thickness of each of said explosives being at least 0.2 mm. and such as to exceed the minimum thickness for support of the detonation, each of said explosive layers being separated one from another by a barrier plate provided with an array of detonation-transmitting channels, the barrier plate being of a material having a shock velocity lower than the detonation velocity of the explosive, the array of said channels in successive plates being such that the axis of each channel in a given plate is equidistant from

the axis of each of a plurality of channels in the immediately following plate, said detonation front being initiated at a point within the layer of said cap-sensitive, high explosive most distant from the base surface of said generator..

2. A surface-wave generator according to claim 1, wherein said detonation-transmitting channels are filled with explosive.

3. A surface-wave generator according to claim 1, wherein said detonation-transmitting channels are air-filled.

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