



Description

The invention relates to a method for marine seismic exploration, in which a seismic source array comprising a plurality of seismic sources (acoustic wave generators) is used, and comprising the steps of synchronously discharging the seismic sources and producing an energy spectrum resulting from the simultaneous actuation of all seismic sources.

Such a method is known from U.S. 3,437,170.

According to U.S. 3,437,170 detectors are located in a continuously towed streamer cable, which extends from the rear of a towing vessel, and detect the acoustic waves, reflected from subsurface formations, while the vessel is proceeding along a prescribed course over the area of interest.

A plurality of seismic sources belonging to an array, in particular an array of air-guns, are used and a plurality of acoustic waves are generated simultaneously from such an array in order to provide a composite acoustic wave of satisfactory amplitude and frequency content. Air-guns having various volume capacities are used in such arrays in order to produce a composite acoustic wave having a broad frequency band, as air-guns of various volumes generated acoustic waves with different frequency spectrum and corresponding phase spectrum, the frequency content and in particular the fundamental frequency of the generated acoustic wave being dependent upon the volume capacity of the air-gun.

However, the method of U.S. 3,437,170 is not able to provide a full spectrum of high energy acoustic pulses and to generate a number of acoustic waves of various fundamental frequencies.

Further, problems associated with noise appearance and loss of useful acoustic wave energy in water still exist and are not solved satisfactorily by the prior art. For example, meaningful information contained by seismic waves directly reflected from the ocean bottom is often masked due to the reception of horizontally travelling noise caused by reflections of horizontal seismic waves from underwater obstacles and the like. So, high frequency radiations in more horizontal directions should be suppressed to avoid water trapped noise to dominate the seismic record. However, after this it might well be that still a significant amount of additional energy is needed to overcome the streamer noise and to compensate for non-elastic losses.

Further present day air-gun arrays are designed to emit short signals to improve the spectrum of the signal and its determination. This may be achieved by cancelling the "tail energy" of the signal which is partly a destructive exercise and physically means a loss of possible useful energy.

Accordingly, it is an object of the present

invention to provide a method for marine seismic exploration, which provides seismic signals of high quality. More particularly, it is an object of the method according to the present invention to provide an improved signal-to-noise ratio of the seismic signals. Further, it is another object of the present invention to provide a method for marine seismic exploration which reduces the loss of useful acoustical energy.

Still another object of the invention is providing a method for marine seismic exploration, allowing amplification of the energy in a determined frequency band, particularly high frequency energy.

Still another object of the invention is providing a satisfactory signal by means of smaller air quantities than according to the conventional techniques.

Still another object of the present invention is providing a method for marine seismic exploration, which achieves an increase in effective source strength.

In a method according to the precharacterising part of claim 1 the invention is therefore characterized by the steps comprised in the characterising part of claim 1.

In an advantageous embodiment of the invention air-guns may be used as seismic sources. In the following explanation the term "air-gun" will be used, but it should be clear that the invention is not restricted thereto.

The invention is in particular based upon the application of phenomena known as "frequency multiplexing the shot's energy" and "zero-phasing prior to final summation" or "stacking". "Stacking" as such is a known technique of processing seismic signals and will not be described further. "Frequency multiplexing of shot energy" is a way of rearranging in time and frequency the emission of shot energy.

The "frequency multiplexed" mode of shooting implies first discharging simultaneously a determined number of guns having a volume V_1 , followed by discharging simultaneously a determined number of guns having a volume V_2 , etc.

The guns may be divided in groups, each group consisting of guns having a same determined volume. It should be emphasized that the number of the guns to be discharge of each group may vary so $4 V_1$, $5 V_2$, $6 V_3$, etc. may be discharged during the operation.

In an advantageous embodiment of the invention only one group of air-guns having an adjustable volume or an adjustable operating pressure may be used.

The simultaneous discharging of a determined number of airguns having a determined volume results in the same number of acoustic wave fronts having a substantially identical form, which acoustic waves interfere with each other resulting in a sum wave with a frequency range depending upon the size of the individual equivalent volumes of the said air-guns, and are

subsequently detected by a hydrophone. Thus, during the shooting procedure several separate sum signals are obtained, each sum signal having a determined mutually different frequency range. So, in the "frequency multiplex" mode a determined number of times more energy in one determined frequency range per shot is applied by using a determined number of times more identical guns and thus producing a determined number of times more signal amplitude in that particular frequency range per shot. Thus, rather than producing a full spectrum with each shot, which is a conventional method using air guns having different sizes which are discharged simultaneously, the invention emphasizes the respective determined frequency ranges sequentially but with a determined number of times higher specific energy input per determined frequency range.

The respective separate sum signals each having a determined frequency range are filtered in any suitable way to remove noise outside the said determined frequency range and to eliminate certain phase shifts, which may exist in the frequency range of each individual obtained sum signal, by any suitable phase shift operation to avoid a destructive interference because of overlapping signal spectra with different phase spectra. This has to be carried out in such a way that the separate sum signals are "zero-phase processed" which means that the said sum signals are converted into their zero-phase equivalent by means of a suitable zero-phase operator. The zero-phase operator has to be derived from the shape of the actual outgoing signal (which is the undistorted signal without noise). For this purpose for example the nearby signal, obtained by firing only one gun or a plurality of identical guns, may be used.

In this way the whole spectral band is aligned before final summation or "stacking", so that all energy stacks in phase.

The several signal processing operations after the seismic waves having been detected by the hydrophones and converted into electric signal may be carried out by a computer.

Subsequently, the obtained signals are "stacked" together to a final sum signal covering the whole frequency range of interest.

The present invention will now be described by way of example in more detail with reference to the drawings, in which:

Fig. 1 represents schematically an example of a conventional marine seismic exploration system.

Fig. 2 represents several examples of idealized frequency curves of the shot energy of an air-gun array obtained according to the conventional shooting technique.

Fig. 3a represents several examples of idealized frequency curves of the shot energy of an air-gun array obtained according to the method of the invention.

Fig. 3b represents an example of real frequency curves of fig. 3a.

Figs. 4a and b represent examples of the summation of signals derived from an array of air-guns, in this example a 7-gun array.

Fig. 4a shows the conventional summation, whereas fig. 4b shows the "zero-phasing" prior to final summation or "stacking" according to the invention.

Referring now to fig. 1, an example of a conventional marine seismic exploration system is shown.

A marine vessel 1 towing a cable 2 is shown, along which cable a plurality of floats 3a—d are affixed at spaced intervals. Floats of any design or configuration suitable for the purpose may be used in the application of the invention. It will be clear for those skilled in the art that any desired number of floats may be used. The cable 2, which is used for pulling the floats through the water may be connected to the towing vessel 1 in any manner suitable for the purpose, for example such as by means of a reel, which is controlled by a suitable motor.

Seismic sources 4a—d, for example air-guns, are attached by suitable links from respective ones of the floats 3a—d. It will be clear for those skilled in the art that each float may carry an array of seismic sources consisting of a plurality of air-guns. To each air-gun compressed air or other suitable high-pressure fluid may be fed via a line 8, comprising high-pressure conduits and electric leads for transmission of signals which may be attached at one end to a compressor (not shown), located aboard the vessel 1. It will be clear that also separate lines for each air-gun may be used, if desirable. The vessel 1 also tows a cable 5 being attached to a streamer 6 which contains a plurality of acoustic receivers such as hydrophones, which emit electric signals in response to the reception of acoustical reflection of the acoustic waves from the air-guns 4a—d. The cable 5 comprises the required electric leads (not shown), for the transmission of electric signals. The streamer 6 may be provided with equipment known per se, such as electronic signal amplifiers, control equipment for controlling the towing depth, and means for controlling the course of the streamer. The electric signals are received onboard the towing vessel 1 and are subsequently recorded by means of suitable equipment, such as electric amplifiers, filters and recorders (not shown since known per se) and the electric leads of the cable 5.

It will be clear for those skilled in the art that the above procedure is not the only one being possible. For example, the seismic source array may be towed by a first marine vessel whereas, if desired, a second marine vessel may tow the streamer cable provided with the detectors.

More than one streamer may be used for receiving the wave reflections returning from the area being investigated. The streamers may be towed in side-relationship, or one behind the other, or in any other configuration suitable for the purpose.

The cable 5 may be connected to the towing vessel in any manner suitable for the purpose, such as by means of rotatable cable drums. Further, any amount and configuration of seismic sources that is suitable for the purpose may be applied. The same applies for the type of seismic source used.

Referring now to fig. 2 the amplitudes A_i ($i=1-N_2$) of a certain number of acoustic seismic pulses as obtained according to the conventional method of subsequently shooting of a set of different volume air-guns (vertical axis) as a function of frequency f (horizontal axis) are represented. It is assumed that the acoustical pulses are obtained in an environment with uncorrelated ambient noise. The ambient noise level R_i ($i=1-N_2$) is also represented. The signals obtained by subsequent shots (1 to N_2) are represented below each other, whereas the signal S represented at the bottom is a summation of the signals, obtained by the subsequent shots. Any number of subsequent shots suitable for the purpose may be possible.

As already mentioned in the above in the conventional technique a set of different volume air-guns is discharged simultaneously, the volumes having been chosen such that the total desired frequency spectrum $f_1-f_{N_2}$ is covered. Each individual gun having a determined volume is taking care for a specific part f_i of said spectrum and emits a limited spectral frequency band f_i ($i=1-N_1$) (sub-band) depending upon its volume and the total desired spectrum is the subsequent series of these individual sub-bands f_i . It will be clear that any desired number of guns may be used. From fig. 2 it will be clear that in this example $N_1=N_2=5$.

For the sake of simplicity it is assumed in fig. 2 that each gun emits a rectangular limited spectral band f_i . In general, a number of N_1 guns, each gun having different volume, is used and consequently N_1 sub-bands are covered in discharging simultaneously the N_1 air-guns having different volume. This procedure is repeated N_2 times which results in N_2 shot records of the total spectrum and subsequently N_2 of these conventional shot records are finally summed, each shot record however being polluted with the same level of ambient noise R_i ($i=1-N_2$).

Compared with a single shot record the signal amplitude A_s in the final sum signal is N_2 times higher while the expectation value for the amplitude V of the noise is $\sqrt{N_2}$ higher which may be shown statistically. In this way a gain of $\sqrt{N_2}$ in signal-to-ambient noise may be achieved.

As already mentioned in the above this process of finally summing the electrical signals which are derived from each of the detectors so as to produce a single signal having a larger amplitude is called "stacking". It will be clear that in practice the signals have no exact rectangular form, but have an oscillating character.

Referring now to fig. 3a the results of the method according to the invention are shown.

The horizontal and vertical axes represent the same quantities amplitude and frequency as in fig. 2. However, with each shot only one frequency range f_i is covered, the amplitude A_i of the signal being larger than in fig. 2.

By discharging simultaneously a predetermined number, for example $n=N_1$ guns, each gun having the same determined volume V_i , N_1 times more energy in one particular sub-band f_i per shot is put, thus producing N_1 times more signal amplitude in that particular sub-band per shot. Thus, rather than producing a full spectrum with each shot which is done by the conventional method, the invention emphasizes the sub-bands f_i sequentially but with a N_1 times higher specific energy input per sub-band. After N_2 shots the entire desired spectrum ($f_1-f_{N_1}$) has been covered. This is represented by the sum signal at the bottom of fig. 3a which shows an equivalent signal amplitude but a $\sqrt{N_2}$ times lower ambient noise level as compared with the conventional method. It will be clear for those skilled in the art that n may have any value suitable for the purpose.

Fig. 3b represents an example of real frequency curves of fig. 3a.

The relative amplitude (vertical axis) has been represented as a function of the frequency in Hertz (horizontal axis).

Any suitable filtering operation may be applied to remove noise from the received signals. This filtering operation may be adapted continuously to the frequency sub-band being used. In an advantageous embodiment of the invention a selective band pass filter may be used.

The gain in the signal-to-noise ratio has been obtained by the selective filtering which allows the ambient background noise to appear only once per sub-band in a series of N_2 recordings.

Another good result of the filtering process is zero-phasing, which will now be described referring to fig. 4a and fig. 4b.

Fig. 4a represents the results of conventional summing of several signals, each signal having its own specific frequency spectrum and phase spectrum to produce an enhanced signal. Fig. 4b represents the results of zero-phasing prior to final summation. The vertical axis represents the amplitude of the signals, whereas the horizontal axis represents time. The examples of Fig. 4a represent from top to bottom signals having a mutually different phase. The final conventional summation of these signals represented by the summation signal at the bottom of fig. 4a provides a signal having a relatively low amplitude.

In this example a 7-gun array has been used, but it will be clear to those skilled in the art that any other suitable number of seismic sources may be used. The sources, each member producing a band limited signal, are combined to produce a broad frequency spectrum. The

spectral shape of the individual gun signals however implies that the spectral- and signal shaping has been achieved with a certain degree of destructive interference, since the guns are producing overlapping signal spectra with different phase-spectra as will be clear from fig. 3b. According to the invention this destructive interference is avoided by firing guns having different volumes individually and convert all signals into their zero-phase equivalent prior to final summation ("stacking").

In this way the whole spectral band is aligned before summation, so that all energy stacks in phase and a larger signal amplitude may be achieved as will be clear from fig. 4b.

As already indicated in the above the real spectrum shape of an air gun is not a square box but has an oscillatory character. A suitable selective filter for the method of the invention may therefore be a band pass filter providing a frequency weighing according to the emitted spectrum.

According to an advantageous embodiment of the invention selective filtering and zero-phasing of the signals may be combined in one process by cross-correlating the trace with the outgoing signal (which is the undistorted signal without surface reflections and without noise). Measurement of the said outgoing signal may be performed in several ways for example by using a calibrated hydrophone suspended from the seismic source. Another possibility is simulating a source signal by means of a suitable computer operation and carrying out a cross-correlation with the received hydrophone signal. Such measurements are known to those skilled in the art and will not be described in detail. Cross-correlation is not only an optimum frequency filter process for signal/noise ratio enhancement, but simultaneously also a zero-phase operator.

It should be emphasized that the detected signals, which are recorded and processed may be obtained by any suitable marine seismic exploration system, using an array of seismic sources.

Various modifications of the invention will become apparent to those skilled in the art from the foregoing description and accompanying drawings. Such modifications are intended to fall within the scope of the appended claims.

Claims

1. A method for marine seismic exploration, in which a seismic source array comprising a plurality of seismic sources in the form of fluid guns having respective fluid volumes is used, comprising the steps of first discharging simultaneously a determined number of seismic sources, each source having a determined fluid volume V_1 , said discharging of these seismic sources having a volume V_1 resulting in several seismic waves with substantially identical form, and after reflection by a series of reflection

points, detecting the reflected waves by hydrophones as a sum signal of the individual emitted source waves having a frequency range f_1 , characterized by subsequently filtering said sum signal by means of a suitable filter operation having a frequency range f_1 , said filtering operation resulting in a sum signal having substantially equal phase of the individual components in the frequency range f_1 , and subsequently discharging simultaneously a determined number of seismic sources having a determined fluid volume V_2 different from the above-mentioned volume V_1 , said discharging of the seismic sources having a volume V_2 resulting in several seismic waves with substantially identical form and, after reflection, detecting the corresponding reflected waves by hydrophones as a sum signal of the individual emitted source waves having a frequency range f_2 , filtering said sum signal by means of a suitable filter operation having a frequency range f_2 , to obtain substantially equal phase of the individual components in the frequency range f_2 , and subsequently repeating the above-mentioned procedure of discharging simultaneously seismic sources having a determined volume, detecting the several seismic waves after reflection and filtering the sum signals in a suitable way with seismic sources having mutually different fluid volumes $V_3, V_4 \dots V_n$ respectively and subsequently stacking the obtained signals, which result in a final stacked sum signal having a frequency range $f_1 \dots f_n$.

2. The method as claimed in claim 1, characterized in that the seismic sources consist of air-guns, which are divided into groups, each group consisting of air-guns having a same determined volume.

3. The method as claimed in claim 2, characterized in that airguns having an adjustable volume or an adjustable operating pressure are used.

4. The method as claimed in any one of claims 2—3, characterized in that the number of air-guns being discharged simultaneously during the operation is always the same.

5. The method as claimed in any one of claims 2—3, characterized in that the number of air-guns being discharged simultaneously during the operation is variable.

6. The method as claimed in any one of claims 1—5, characterized in that the filtering operation takes place by means of a band pass filter.

7. The method as claimed in any one of claims 1—6, characterized in that the filtering operation takes place in such a way that the substantially equal phase of the individual components of a sum signal having a determined frequency range is obtained by means of zero-phasing of the individual sum signals prior to stacking.

8. The method as claimed in claim 7, characterized in that a cross-correlation of the received

spectral shape of the individual gun signals however implies that the spectral- and signal shaping has been achieved with a certain degree of destructive interference, since the guns are producing overlapping signal spectra with different phase-spectra as will be clear from fig. 3b. According to the invention this destructive interference is avoided by firing guns having different volumes individually and convert all signals into their zero-phase equivalent prior to final summation ("stacking").

In this way the whole spectral band is aligned before summation, so that all energy stacks in phase and a larger signal amplitude may be achieved as will be clear from fig. 4b.

As already indicated in the above the real spectrum shape of an air gun is not a square box but has an oscillatory character. A suitable selective filter for the method of the invention may therefore be a band pass filter providing a frequency weighing according to the emitted spectrum.

According to an advantageous embodiment of the invention selective filtering and zero-phasing of the signals may be combined in one process by cross-correlating the trace with the outgoing signal (which is the undistorted signal without surface reflections and without noise). Measurement of the said outgoing signal may be performed in several ways for example by using a calibrated hydrophone suspended from the seismic source. Another possibility is simulating a source signal by means of a suitable computer operation and carrying out a cross-correlation with the received hydrophone signal. Such measurements are known to those skilled in the art and will not be described in detail. Cross-correlation is not only an optimum frequency filter process for signal/noise ratio enhancement, but simultaneously also a zero-phase operator.

It should be emphasized that the detected signals, which are recorded and processed may be obtained by any suitable marine seismic exploration system, using an array of seismic sources.

Various modifications of the invention will become apparent to those skilled in the art from the foregoing description and accompanying drawings. Such modifications are intended to fall within the scope of the appended claims.

Claims

1. A method for marine seismic exploration, in which a seismic source array comprising a plurality of seismic sources in the form of fluid guns having respective fluid volumes is used, comprising the steps of first discharging simultaneously a determined number of seismic sources, each source having a determined fluid volume V_1 , said discharging of these seismic sources having a volume V_1 resulting in several seismic waves with substantially identical form, and after reflection by a series of reflection

points, detecting the reflected waves by hydrophones as a sum signal of the individual emitted source waves having a frequency range f_1 , characterized by subsequently filtering said sum signal by means of a suitable filter operation having a frequency range f_1 , said filtering operation resulting in a sum signal having substantially equal phase of the individual components in the frequency range f_1 , and subsequently discharging simultaneously a determined number of seismic sources having a determined fluid volume V_2 different from the above-mentioned volume V_1 , said discharging of the seismic sources having a volume V_2 resulting in several seismic waves with substantially identical form and, after reflection, detecting the corresponding reflected waves by hydrophones as a sum signal of the individual emitted source waves having a frequency range f_2 , filtering said sum signal by means of a suitable filter operation having a frequency range f_2 , to obtain substantially equal phase of the individual components in the frequency range f_2 , and subsequently repeating the above-mentioned procedure of discharging simultaneously seismic sources having a determined volume, detecting the several seismic waves after reflection and filtering the sum signals in a suitable way with seismic sources having mutually different fluid volumes $V_3, V_4 \dots V_n$ respectively and subsequently stacking the obtained signals, which result in a final stacked sum signal having a frequency range $f_1 \dots f_n$.

2. The method as claimed in claim 1, characterized in that the seismic sources consist of air-guns, which are divided into groups, each group consisting of air-guns having a same determined volume.

3. The method as claimed in claim 2, characterized in that airguns having an adjustable volume or an adjustable operating pressure are used.

4. The method as claimed in any one of claims 2—3, characterized in that the number of air-guns being discharged simultaneously during the operation is always the same.

5. The method as claimed in any one of claims 2—3, characterized in that the number of air-guns being discharged simultaneously during the operation is variable.

6. The method as claimed in any one of claims 1—5, characterized in that the filtering operation takes place by means of a band pass filter.

7. The method as claimed in any one of claims 1—6, characterized in that the filtering operation takes place in such a way that the substantially equal phase of the individual components of a sum signal having a determined frequency range is obtained by means of zero-phasing of the individual sum signals prior to stacking.

8. The method as claimed in claim 7, characterized in that a cross-correlation of the re-



hydro-phone signal with the undistorted measured source signal takes place.

9. The method as claimed in claim 7, characterized in that a cross-correlation of the received hydrophone signal with a computer-simulated source signal takes place.

Revendications

1. Un procédé d'exploration sismique marine dans lequel on utilise un réseau de sources sismiques comprenant plusieurs sources sismiques constituées par des canons à fluide ayant des volumes de fluide respectifs, qui comprend les étapes qui consistent à décharger tout d'abord simultanément un nombre déterminé de sources sismiques, chaque source ayant un volume de fluide déterminé V_1 , ladite décharge de ces sources sismiques qui ont un volume V_1 produisant plusieurs ondes sismiques ayant une forme sensiblement identique et, après réflexion par une série de points de réflexion, à détecter au moyen d'hydrophones les ondes réfléchies sous forme d'un signal de somme des ondes émises par les sources individuelles ayant un intervalle de fréquences f_1 , caractérisé en ce qu'il consiste à filtrer ensuite ledit signal de somme, au moyen d'une opération de filtrage appropriée, le filtre ayant un intervalle de fréquences f_1 , cette opération de filtrage produisant un signal de somme dans lequel les composantes individuelles dans l'intervalle de fréquences f_1 ont sensiblement la même phase, et à décharger en suite simultanément un nombre déterminé de sources sismiques ayant un volume de fluide déterminé V_2 différent du volume V_1 ci-dessus mentionné, ladite décharge des sources sismiques ayant un volume V_2 produisant plusieurs ondes sismiques ayant une forme sensiblement identique et, après réflexion, à détecter les ondes réfléchies correspondantes sous forme d'un signal de somme des ondes émises par les sources individuelles ayant un intervalle de fréquences f_2 , à filtrer ledit signal de somme au moyen d'une opération de filtrage appropriée, le filtre ayant un intervalle de fréquences f_2 , pour obtenir une phase sensiblement égale des composantes individuelles dans l'intervalle de fréquences f_2 , puis à répéter le processus ci-dessus qui consiste à décharger simultanément des sources sismiques ayant un volume déterminé, à détecter les diverses ondes sismiques après réflexion et à filtrer les signaux de somme d'une manière appropriée, avec des sources sismiques ayant des volumes de fluide différents les uns des autres, respectivement V_3 , V_4 — V_n et à superposer ensuite les signaux obtenus, ce qui produit un signal de somme superposé final ayant un intervalle de fréquences f_1 — f_n .

2. Le procédé tel que revendiqué dans la revendication 1, caractérisé en ce que les sources sismiques sont constituées par des

canons à air comprimé qui ont été divisés en groupes, chaque groupe étant composé de canons à air comprimé ayant le même volume déterminé.

3. Le procédé tel que revendiqué dans la revendication 2, caractérisé en ce qu'on utilise des canons à air comprimé qui ont une volume réglable ou une pression de fonctionnement réglable.

4. Le procédé tel que revendiqué dans l'une quelconque des revendications 2 et 3, caractérisé en ce que le nombre de canons à air comprimé qui est déchargé pendant le fonctionnement est toujours le même.

5. Le procédé tel que revendiqué dans l'une quelconque des revendications 2 et 3, caractérisé en ce que le nombre de canons à air comprimé qui est déchargé pendant le fonctionnement est variable.

6. Le procédé tel que revendiqué dans l'une quelconque des revendications 1 à 5, caractérisé en ce que l'opération de filtrage est effectuée moyen d'un filtre passe-bande.

7. Le procédé tel que revendiqué dans l'une quelconque des revendications 1 à 6, caractérisé en ce que l'opération de filtrage est effectuée d'une manière telle que la phase sensiblement égal des composantes individuelles d'un signal de somme ayant un intervalle de fréquences déterminée est obtenu au moyen de calage au point zéro des phases des signaux de somme individuelle avant la "superposition".

8. Le procédé tel que revendiqué dans la revendication 7, caractérisé en ce qu'une auto-corrélation du signal d'hydrophones reçu avec le signal de source mesuré non déformé est effectuée.

9. Le procédé tel que revendiqué dans la revendication 7, caractérisé en ce qu'une auto-corrélation du signal d'hydrophones reçu avec un signal de source simulée par ordinateur est effectuée.

Patentansprüche

1. Verfahren für die seismische Ozeanforschung, bei dem eine seismische Quellenreihe, die eine Vielzahl seismischer Quellen in Form von Fluidum-Kanonen mit betreffenden Fluidum-Volumina umfaßt, verwendet wird und bei dem zuerst eine bestimmte Zahl seismischer Quellen mit einem bestimmten Fluidum-Volumen V_1 entladen wird, wobei die Entladung dieser seismischen Quellen mit einem Volumen V_1 zu mehreren seismischen Wellen mit weitgehend identischer Form führt und nach Reflektion an einer Reihe von Reflektionspunkten die reflektierten Wellen mittels Hydrophonen als Summen-Signal der einzeln emittierenden Quellen-Wellen mit einem Frequenzbereich f_1 aufgezeichnet werden, dadurch gekennzeichnet, daß das Summen-Signal anschließend mittels einer geeigneten



Filter-Operation mit einem Frequenzbereich f_1 , gefiltert wird, wobei die Filteroperation zu einem Summen-Signal führt, bei dem die einzelnen Komponenten in dem Frequenzbereich f_1 , weitgehend gleiche Phase aufweisen, daß anschließend simultan eine bestimmte Zahl seismischer Quellen mit einem bestimmten Fluidum-Volumen V_2 , das von obigen Volumen V_1 verschieden ist, entladen wird, wobei die Entladung dieser seismischen Quellen mit einem Volumen V_2 zu verschiedenen seismischen Wellen mit weitgehend identischer Form führt, daß nach Reflektion die entsprechenden reflektierten Wellen mittels Hydrophonen als ein Summen-Signal der einzeln emittierten Quellen-Wellen mit einem Frequenzbereich f_2 aufgezeichnet werden und das Summen-Signal mittels einer geeigneten Filter-Operation mit einem Frequenzbereich f_2 gefiltert wird, um die einzelnen Komponenten in weitgehend gleicher Phase im Frequenzbereich f_2 zu erhalten, und daß anschließend das Verfahren der simultanen Entladung seismischer Quellen mit einem bestimmten Volumen das Aufzeichnen von mehreren seismischen Wellen nach der Reflektion und das Filtern des Summen-Signals auf geeignete Weise mit seismischen Quellen, die gegenseitig verschiedene Fluidum-Volumina $V_3, V_4, \dots, V_n$ haben, wiederholt wird und anschließend die erhaltenen Signale aufsummiert werden, was schließlich zu einem aufsummierten Summen-Signal mit einem Frequenzbereich von $f_1, \dots, f_n$ führt.

2. Verfahren nach Anspruch 1, dadurch gekennzeichnet, daß die seismischen Quellen aus Druckluft-Kanonen bestehen, welche in zwei Gruppen unterteilt sind und jede Gruppe

Druckluft-Kanonen mit demselben bestimmten Volumen umfaßt.

3. Verfahren nach Anspruch 2, dadurch gekennzeichnet, daß die Druckluft-Kanonen ein einstellbares Volumen haben oder ein einstellbarer Arbeitsdruck angewendet wird.

4. Verfahren nach einem der Ansprüche 2 bis 3, dadurch gekennzeichnet, daß die Zahl der Druckluft-Kanonen, die während des Verfahrens simultan entladen werden, stets dieselbe ist.

5. Verfahren nach einem der Ansprüche 2 bis 3, dadurch gekennzeichnet, daß die Zahl der Druckluft-Kanonen, die während des Verfahrens entladen werden, variabel ist.

6. Verfahren nach einem der Ansprüche 1 bis 5, dadurch gekennzeichnet, daß die Filter-Operation mittels eines Bandpaßfilters durchgeführt wird.

7. Verfahren nach einem der Ansprüche 1 bis 6, dadurch gekennzeichnet, daß die Filter-Operation so durchgeführt wird, daß eine weitgehend gleiche Phase der einzelnen Komponenten eines Summen-Signals mit einem bestimmten Frequenzbereich mittels Null-Phasensetzung der einzelnen Summen-Signale vor dem Aufsummieren erhalten wird.

8. Verfahren nach Anspruch 7, dadurch gekennzeichnet, daß eine Kreuz-Korrelation des empfangenen Hydrophon-Signals mit dem ungestörten gemessenen Quellen-Signal durchgeführt wird.

9. Verfahren nach Anspruch 7, dadurch gekennzeichnet, daß die Kreuz-Korrelation des empfangenen Hydrophon-Signals mit einem computersimulierten Quellen-Signal durchgeführt wird.

