

PATENT SPECIFICATION

(11) 1349 496

1349 496

- (21) Application No. 11994/72 (22) Filed 15 March 1972
 (31) Convention Application No. 127110 (32) Filed 23 March 1971 in (19)
 (33) United States of America (US)
 (44) Complete Specification published 3 April 1974
 (51) International Classification G01V 1/28
 (52) Index at acceptance
 H4D G1G2 G3B G3P G3R G7P



(54) DETERMINATION OF RESPONSE AND PASSBAND OF SEISMIC DATA GATHERING SYSTEM

(71) We, MOBIL OIL CORPORATION, a corporation organized under the laws of the State of New York, United States of America, of 150 East 42nd Street, New York, New York 10017, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to a process of determining the response (as herein defined) and passband of a seismic data gathering system used in obtaining a number of traces recorded with known receiver offset distances relative to a shotpoint.

In seismic operations, common depth point stacking of CDP gathered data has become widely used as a technique for enhancing primaries and attenuating multiples. In this process, the CDP traces of a given set are corrected for normal moveout or time, to allow primaries to be stacked in phase. This enhances the primaries and attenuates the multiples.

The spread configuration used in gathering the data also plays an important part in determining the effectiveness in which multiples are attenuated. For example, different spread configurations will result in greater attenuation of multiples in a given area. In this respect, the need arises to determine the efficiency of a given spread in attenuating multiples; in other words, to find whether the particular spread configuration used in the area under consideration resulted in the satisfactory attenuation of multiples. If not, then a new spread design may be desirable.

In the processing of the gathered data, the normal moveout corrections made are based upon a time-velocity curve of primaries, which in any area may be estimated or determined from velocity surveys made in nearby wells. The same general curve may be used over a wide area for normal moveout correction.

In certain regions, however, subsurface anomalies occur and the general time-velocity

curve is not applicable. In these regions, the correct velocity is needed for stacking purposes, for example, to map the edges of salt domes and shale masses.

By means of additional velocity surveys or velocity searching techniques, additional velocity information in the areas of the anomalies may be obtained. The question arises as to whether it is desirable to restack the data in the light of the new velocity information. Thus the need arises to determine the passband or response for all times and velocities, of the stacking filter comprising the spread configuration.

The term "response" is used herein in the sense of a transmission-characteristic of a filter, to indicate the degree to which the representation of a signal is reproduced in the output of the filtering operation constituted by stacking. The invention is particularly concerned with a *relative response*, defined as the power ratio of a stacked wavelet with a given velocity error to a stacked wavelet with no velocity error.

In accordance with the present invention there is provided a process carried out in an automatic computing system, of determining the response as herein defined of a seismic spread configuration used in obtaining a plurality of seismic traces recorded with known source-receiver offset distances, comprising:—
 (a) shifting and stacking a wavelet, taken from each of N traces of interest, in phase to produce a reference power/time response, using a correct velocity for that wavelet; (b) at a given record time at which said wavelet occurs on one trace computing the moveout for each said trace of interest using a velocity value differing from said correct velocity by a predetermined velocity error; (c) shifting said wavelet relative to said record time in accordance with each moveout computed, and stacking the shifted wavelets to produce an error power/time response; and (d) forming the ratio between said error response and said reference response, to form a relative response.

Preferably said wavelet is stacked in deter-

mining said reference response and said error response only for traces recorded with offset distances less than $V.T$, where T is said given record time, and V is the subsurface velocity at T .

In accordance with an embodiment of the invention, steps (a) to (d) are repeated for a plurality of record time and correct velocities to form an array of relative responses, and the relative responses are contoured to form a map having co-ordinates of time and velocity and a plurality of different contour lines each connecting points of equal relative response.

The above steps may be carried out for a series of different errors in velocity to form a plurality of error response maps.

Knowing the velocity of multiples and of primaries at a given record time, one can then employ these maps to determine if the particular spread configuration used in the area resulted in the satisfactory attenuation of multiples.

In accordance with a further embodiment of the present invention, there is provided a method wherein steps (a) to (d) are repeated for a range of values of velocity error until the relative response formed corresponds with that defining a predetermined velocity bandwidth. This method is preferably applied at a plurality of time-velocity co-ordinate points along a function $F(T,V)$ defining the variation of subsurface velocity with time, to determine one or more bandwidth functions which define the passband limits of a predetermined velocity passband about said function $F(T,V)$. Only those traces which contribute to a determination of velocity are employed in determining the passband.

Knowing this passband about the curve in time-velocity space, then one can determine if the time-velocity curve employed in stacking falls within the passband. If the stacking curve falls outside of the passband, then improvements can be obtained by stacking the data with a time-velocity curve which falls within the passband.

The band-width function obtained is employed to determine a number of velocity sampling points within a velocity range about said function $F(T,V)$. Of interest is the location of the peak response within this range which reflects the best estimate of velocity. The velocity searching increments determined are sufficient to place at least two velocity sampling points within the passband whereby the peak response may be adequately located using polynomial interpolation.

The invention will now be further described with reference to the accompanying drawings in which:—

FIGURE 1 illustrates a wavelet used in obtaining the response of a spread configuration for no velocity error and for a given velocity error.

FIGURE 2 is a relative response map for a given error in velocity in time-velocity space.

FIGURE 3 is a response curve representative of the relative response of a seismic spread at a single time-velocity point as a function of velocity error.

FIGURE 4 is the passband of a seismic spread in time-velocity space.

FIGURE 5 illustrates a time-velocity function having a velocity range about the function which is to be searched at velocity increments within each of a plurality of time windows.

FIGURE 6 is a flow diagram of the basic steps carried out in determining the passband and velocity searching increments employed to search in the velocity range illustrated in FIGURE 5.

FIGURES 7A to 7C are a printout of the time-velocity passband obtained with a number of effective traces computed from twelve-fold data.

In CDP gathered data, the assumption is made that the reflections from a common reflector will appear across the traces. This is illustrated in FIGURE 1 wherein X_1 — X_4 represent the traces, and the wavelets or sine functions 20 represent the reflections. They appear centered on the curve 22. By properly correcting each wavelet (normal moveout correction), they may be stacked in phase to obtain a maximum power/time response illustrated at 23.

If one now assumes a slight error in velocity, for example, that which defines the curve 24 for lower velocity, and uses this velocity or curve to correct the wavelets 20, they will be over-corrected to the positions illustrated in dotted form. When these over-corrected wavelets are stacked, they will be stacked out of phase and the resulting response will be degraded or less than a maximum. Such a degraded response is illustrated at 25 in FIGURE 1.

The moveout correction DT based upon a given velocity error may be expressed as follows:

$$DT = T - \sqrt{X^2/V^2 - X^2/(V^2(1+\epsilon)^2)} + T^2(1)$$

where,

T is record time,

X is source-detector offset distance,

V is correct velocity, and

ϵ is the velocity error.

If epsilon is zero, then there is no velocity error and the moveout error is zero. Thus, a number NTR of the wavelets 20 may be summed in phase at time T , (NTR equals the number of traces) to obtain a correct or perfect stack and hence a maximum response 23.

When ϵ assumes a positive value, then the moveout correction DT will shift the wavelets to one side of the time point T to obtain

the degraded response when stacked. Similarly, when ϵ assumes a negative value, the moveout correction DT will shift the wavelets to the other side of the time point T, and a degraded response also will be obtained. Continued increase in velocity error ϵ on either side (plus or minus) of the correct velocity will result in a decreasing response.

The maximum response for a correct stack may be defined as SAM, while a degraded response for a stack with a given velocity error may be defined as SU. The ratio SU/SAM is the relative response obtained for a given T, V, and ϵ when applied to a given spread configuration having given offset distances.

In one embodiment of the present invention, a grid or an array of relative response values for a plurality of times and correct velocities is formed for a given velocity error ϵ and a given spread configuration. Relative response points of equal value then are contoured to form a contoured relative response map in time-velocity space for a given velocity error ϵ . Such a map is illustrated in part in FIGURE 2. It was obtained with a program called ERRT. This same program obtains a series of such maps, each for a different velocity error. These maps may be employed to determine the efficiency of the field gathering system in attenuating multiples as will be explained subsequently.

In obtaining the map of FIGURE 2, the trace distances of the field gathering system are read in or employed and a range of times and velocities is specified. This is the range over which the investigation is going to be made. The time and velocity ranges then are broken down into increments to form a grid or array of time and velocity coordinate points. A portion of the grid or coordinate points is illustrated at the lower left of FIGURE 2. The ERRT program used a grid of 20x20 coordinate points.

A velocity error then is assigned, for example, 16% ($\epsilon = .16$). A maximum response SAM for a correct stack is computed. In one embodiment, SAM is obtained by stacking a number of the wavelets 20 in phase equal to the number of traces in the CDP set employed, for example, 24 traces. The program ERRT actually forms the power of the stacked wavelets for SAM and SU.

Equation (1) is then employed to form the degraded response SU at one point on the grid, for example, grid point (1, 1). The velocity and time at this point and the velocity error 16% are applied to Equation (1) to compute DT for each of the trace distances. These DT values shift the wavelets 20 to 24 different positions (assuming 24 traces are used) as a function of the velocity error ϵ . The shifted wavelets then are formed to determine SU for the coordinate point (1, 1). SU/SAM then is determined for this point.

The velocity V and velocity error ϵ then are held constant, T is incremented, and SU, and hence SU/SAM, is computed for co-ordinated point (2, 1). These computations are done for all of the coordinate points in the first column. The velocity is then incremented and SU/SAM is computed for the coordinate points in the second column. In this manner, SU/SAM is computed for all of the coordinate points in the array.

A contour program then is employed to form contour lines connecting together relative response points of equal amplitude. This may be done by interpolation between grid or coordinate points.

These contour lines are illustrated in FIGURE 2. In one embodiment, the relative response points are contoured at 5% intervals. The 95% contour line is illustrated at 26, the 90% contour line at 27, etc. The space to the right of contour line 26 represents maximum or unity response.

A series of the maps of FIGURE 2 may be made for different errors in velocity. For example, 17 maps may be made at 2% intervals of velocity error from minus 16% error to plus 16% error. For no error, the map will be blank.

As indicated above, these maps may be used to determine the response as defined herein of a given spread configuration, having known trace distances. Of interest may be the amount of multiple attenuation obtained with a given spread configuration at a given record time. From prior knowledge and interpretation of record sections, it may be known that at a given record time, the primaries and multiples have a certain value in velocity. For example, assume that at record time of one second, the primaries have a velocity of 9500 feet per second and the multiples have a velocity of 8930 feet per second. The multiples thus have a velocity of 6% less than that of the primaries at that time, i.e., $(9500 - 8930)/9500 = 6\%$ ($\epsilon = -.06$).

One may then obtain the response map that was made for events that were stacked at a velocity 6% lower than true velocity to determine the stacking response for that spread configuration at a record time of one second. For example, assume the map of FIGURE 2 was computed for a velocity error of minus 6%. Then at record time of one second and at a velocity of 8930 feet per second, one sees from FIGURE 2 that a point is obtained on the map between the 75% and 80% contour. Thus, one knows that at record time of one second, the multiples will stack at a relative response of between 75%—80% compared to the response of the primaries which is unity. One may thus feel that the spread configuration is not doing an adequate job in attenuating multiples at that time and a redesign of the spread configuration may be in order. For example, one may be using a

4,000-foot spread with a 300-foot spacing between receivers. Upon redesign, one may want a longer spread or one that did not have as many detectors near zero distance.

5 After redesign, traces from the new spread configuration may be run through the program again to determine if its response is satisfactory.

10 The above process for forming the maps of the types illustrated in FIGURE 2 is carried out using all times and velocities and may be employed for use anywhere that the particular spread is used.

15 In a preferred feature of the present invention, for a specific time and velocity the above maps may be employed to obtain the relative response as a function of error in velocity. Of interest is the .70 or 70% passband of a stacking filter comprising the spread configuration. This is desired for all times and velocities. The 70% passband about a given time-velocity point and for a given spread configuration is illustrated at 30 in FIGURE 3. One half of this bandpass is identified as 20 DV. Curve 32 is a plot of the relative response of a stacking filter (made up of the spread configuration) as a function of error in velocity. As indicated above, the relative response may be defined as the power ratio of a stacked wavelet with a given velocity error to a stacked wavelet with no velocity error. At RLAA, the relative response is a maximum of unity. The correct velocity for this point is VC. On each side of VC the error in velocity 25 increases whereby the relative response decreases.

30 The same passband 30 of the same time-velocity point of FIGURE 3 is illustrated also in FIGURE 4. In this figure, curve 34 represents the variation of subsurface velocity as a function of time or depth. The 70% passband about this curve at all times and velocities lies between the curves 36 and 38. This passband is useful in determining whether the traces of the record section have been normal moveout corrected and stacked satisfactorily.

40 For example, in a given area the general shape if a time-velocity curve is known from prior knowledge or it is estimated. It may have the shape illustrated by line or curve 40 in FIGURE 4. Assume that the traces are normal moveout corrected and stacked based upon the curve 40. Subsequently, a detailed velocity analysis or velocity search is performed and the correct time-velocity curve is found to be that of 34. A velocity searching technique to obtain good estimates of velocity is described in "Velocity Spectra—Digital Computer Derivation of Velocity Functions" 55 by M. Turhan Taner and Fulton Koehler, presented at the 47th Annual Meeting of the Society of Exploration Geophysicists, Oklahoma City, November 2, 1967.

60 The question arises, does one obtain im-

provement by restacking the data based upon the new curve 34? If the stacking curve 40 falls within the band limits defined by curves 36 and 38, a great deal will not be gained by restacking the data. If, however, the stacking curve 40 falls outside of the band limits, then improvements are expected, especially in the shallow data. Thus, in the shallow regions, the data should be restacked using a time-velocity curve that falls within the band limits.

70 The band limits also give one information as to the velocity increments to use when performing velocity searches in order to properly sample the velocity within the passband. This is desired in order to determine the correct velocities. Having determined a time-velocity curve 34 from the traces of a given CDP set, one knows that the velocity in the same region is going to vary about that curve. Instead of performing a broad velocity search at all record times on every CDP set, one may estimate a velocity range about the curve 34 and search only within that range in order to optimize the search. The velocity search increments employed within that range, however, should be less than the 70% passband if the peak response is to be found.

80 A process is provided for determining the 70% band width at a plurality of points on a time-velocity curve and for using these band-width values for obtaining the velocity searching intervals within a broad velocity range in order to locate the peak response within the passband. The process comprises 85 a main program which calls a subroutine DTCOMP which, in turn, calls a subroutine ERRT. Instead of a 70% band width, a narrower band width may be computed and employed, for example, a 75% band width.

90 The basic steps of the process are illustrated in the flow diagram of FIGURE 6. The main program is illustrated at 44, DTCOMP at 45, and subroutine ERRT at 46.

95 Read into the main program are a plurality of time-velocity points TMC, VCR, which define, for example, the time-velocity curve 34 of FIGURE 4. Two such points are illustrated in FIGURE 5 at 42 and 43. Also read in with each time-velocity point is one half of a velocity range, VINC.

100 The range VINC is a measure of one's uncertainty and knowledge of the time-velocity curve in a given area having had some initial estimate of velocity, for example, curve 34. One knows that the time-velocity curve is going to vary in a given area so that the range VINC is made wide enough to include all of the variations. The lower limit may be located just above the multiple velocity, and an equal amount is obtained on the upper side of curve 34. The full velocity range thus specifies the width over which the velocity searches will be carried out. As indicated 105 110 115 120 125 130

previously, of interest is the velocity search increments or the number of velocity searches within this range needed to locate the peak response for determining the correct velocity.

It is felt that a sample interval of at most one half the band width is necessary in order to locate the peak response. This will place at least two points within the passband.

The main program calls each CDP set of traces from 1 to NSETS sequentially for operation on those traces. It then increments time, i.e. sample, intervals NFIRST down the record section of the CDP set called. Each sample increment may be of the order of ten samples which may be equivalent to 40 milliseconds. At each new time interval the main program calls the subroutine DTCOMP. At each time interval incremented by the main program, DTCOMP locates a time window on the time-velocity curve within points 42 and 43. One such window is illustrated at 47 between TEZ and TEZZ in FIGURE 5. In FIGURE 6 this operation is illustrated as being done at 50. DTCOMP then defines the velocity range about the time-velocity curve within which velocity searching operations are to be carried out. This is illustrated as being done at 51 in FIGURE 6. It next determines the effective traces to be used in the program as illustrated at 52. Of interest is the use of only those trace portions which do not have refraction effects and which contribute to a determination of correct velocity. DTCOMP then calls subroutine ERRT to compute a passband value DV for the time incremented by the main program. This value is one half the passband. This operation is illustrated at 53 in FIGURE 6.

Subroutine ERRT uses the effective traces determined and for those traces stacks a wavelet in phase and out of phase in accordance with an assigned velocity error, to obtain a reference response and an error response, respectively. The ratio SU/SAM is formed to determine the relative response for the assigned velocity error. The error is incremented and the process repeated until the 70% relative response point is found which defines the passband. Control is transferred back to DTCOMP.

At 54, DTCOMP plots the full width 2DV of the passband. FIGURE 7A to 7C represent an example of a plot of the full passband-width values for two CDP sets of twelvefold data at a plurality of time-velocity points. DTCOMP then uses one half of the passband width to compute the number of velocity sample points and hence the desired searching interval within the velocity range defined. This is illustrated as being done at 55 in FIGURE 6. Using this information, there are computed the normal moveout curves to be used by another program for each sample in the time window. This is illustrated as being done at 56 in FIGURE 6. Control is then

transferred back to the main program and time is incremented down the CDP set and the process repeated.

WHAT WE CLAIM IS:—

1. A process carried out in an automatic computing system, of determining the response as herein defined of a seismic spread configuration used in obtaining a plurality of seismic traces recorded with known source-receiver offset distances, comprising:—

- (a) shifting and stacking a wavelet, taken from each of N traces of interest, in phase to produce a reference power/time response, using a correct velocity for that wavelet;
- (b) at a given record time at which said wavelet occurs on one trace, computing the moveout for each said trace of interest using a velocity value differing from said correct velocity by a predetermined velocity error;
- (c) shifting said wavelet relative to said record time in accordance with each moveout computed, and stacking the shifted wavelets to produce an error power/time response; and
- (d) forming the ratio between said error response and said reference response, to form a relative response.

2. The process according to claim 1 wherein the moveout DT of each trace of interest is computed using the relationship:

$$DT = T - \sqrt{X^2/V^2 - X^2/(V^2(1+\epsilon)^2)} + T^2$$

where

- T is said record time,
- X is the offset distance,
- V is correct velocity, and
- ϵ is the velocity error.

3. The process according to claim 1 or 2 wherein said wavelet is stacked in determining said reference response and said error response only for traces recorded with offset distances less than V.T, where T is said given record time, and V is the subsurface velocity at T.

4. A process according to any preceding claim wherein steps (a) to (d) are repeated for a plurality of record times and correct velocities to form an array of relative responses, and the relative responses are contoured to form a map having co-ordinates of time and velocity and a plurality of different contour lines each connecting points of equal relative response.

5. A process according to claim 4 repeated for a series of different errors in velocity to form a series of maps.

6. A relative response map produced by the process of claim 4.

7. A process according to any of claims 1 to 3 wherein steps (a) to (d) are repeated for a range of values of velocity error until the relative response formed corresponds with



previously, of interest is the velocity search increments or the number of velocity searches within this range needed to locate the peak response for determining the correct velocity. It is felt that a sample interval of at most one half the band width is necessary in order to locate the peak response. This will place at least two points within the passband.

The main program calls each CDP set of traces from 1 to NSETS sequentially for operation on those traces. It then increments time, i.e. sample, intervals NFIRST down the record section of the CDP set called. Each sample increment may be of the order of ten samples which may be equivalent to 40 milliseconds. At each new time interval the main program calls the subroutine DTCOMP. At each time interval incremented by the main program, DTCOMP locates a time window on the time-velocity curve within points 42 and 43. One such window is illustrated at 47 between TEZ and TEZZ in FIGURE 5. In FIGURE 6 this operation is illustrated as being done at 50. DTCOMP then defines the velocity range about the time-velocity curve within which velocity searching operations are to be carried out. This is illustrated as being done at 51 in FIGURE 6. It next determines the effective traces to be used in the program as illustrated at 52. Of interest is the use of only those trace portions which do not have refraction effects and which contribute to a determination of correct velocity. DTCOMP then calls subroutine ERRT to compute a passband value DV for the time incremented by the main program. This value is one half the passband. This operation is illustrated at 53 in FIGURE 6.

Subroutine ERRT uses the effective traces determined and for those traces stacks a wavelet in phase and out of phase in accordance with an assigned velocity error, to obtain a reference response and an error response, respectively. The ratio SU/SAM is formed to determine the relative response for the assigned velocity error. The error is incremented and the process repeated until the 70% relative response point is found which defines the passband. Control is transferred back to DTCOMP.

At 54, DTCOMP plots the full width 2DV of the passband. FIGURE 7A to 7C represent an example of a plot of the full passband-width values for two CDP sets of twelvefold data at a plurality of time-velocity points. DTCOMP then uses one half of the passband width to compute the number of velocity sample points and hence the desired searching interval within the velocity range defined. This is illustrated as being done at 55 in FIGURE 6. Using this information, there are computed the normal moveout curves to be used by another program for each sample in the time window. This is illustrated as being done at 56 in FIGURE 6. Control is then

transferred back to the main program and time is incremented down the CDP set and the process repeated.

WHAT WE CLAIM IS:—

1. A process carried out in an automatic computing system, of determining the response as herein defined of a seismic spread configuration used in obtaining a plurality of seismic traces recorded with known source-receiver offset distances, comprising:—

- (a) shifting and stacking a wavelet, taken from each of N traces of interest, in phase to produce a reference power/time response, using a correct velocity for that wavelet;
- (b) at a given record time at which said wavelet occurs on one trace, computing the moveout for each said trace of interest using a velocity value differing from said correct velocity by a predetermined velocity error;
- (c) shifting said wavelet relative to said record time in accordance with each moveout computed, and stacking the shifted wavelets to produce an error power/time response; and
- (d) forming the ratio between said error response and said reference response, to form a relative response.

2. The process according to claim 1 wherein the moveout DT of each trace of interest is computed using the relationship:

$$DT = T - \sqrt{X^2/V^2 - X^2/(V^2(1+\epsilon)^2)} + T^2$$

where

- T is said record time,
- X is the offset distance,
- V is correct velocity, and
- ϵ is the velocity error.

3. The process according to claim 1 or 2 wherein said wavelet is stacked in determining said reference response and said error response only for traces recorded with offset distances less than V.T, where T is said given record time, and V is the subsurface velocity at T.

4. A process according to any preceding claim wherein steps (a) to (d) are repeated for a plurality of record times and correct velocities to form an array of relative responses, and the relative responses are contoured to form a map having co-ordinates of time and velocity and a plurality of different contour lines each connecting points of equal relative response.

5. A process according to claim 4 repeated for a series of different errors in velocity to form a series of maps.

6. A relative response map produced by the process of claim 4.

7. A process according to any of claims 1 to 3 wherein steps (a) to (d) are repeated for a range of values of velocity error until the relative response formed corresponds with

that defining a predetermined velocity band-width.

5 8. A process according to claim 7 wherein the 70 per cent relative response defines the predetermined band-width.

9. A process according to claim 7 or 8 which is applied at a plurality of time-velocity co-ordinate points along a function $F(T,V)$ defining the variation of subsurface velocity with time, to determine one or more band-width functions which define the pass-band limits of a predetermined velocity pass-band about said function $F(T,V)$.

10 10. Computer output means representing the response as herein defined, of a seismic spread configuration and obtained according to the

process of claim 9 in the form of said band-width functions.

11. The process according to claim 9 wherein said band-width function is employed to determine a number of velocity sampling points within a velocity range about said function $F(T,V)$. 20

12. A process according to claim 1 substantially as described with reference to the accompanying drawings. 25

For the Applicants,
CARPMAELS & RANSFORD,
Chartered Patent Agents,
43 Bloomsbury Square, London, WC1A 2RA.

Printed for Her Majesty's Stationery Office, by the Courier Press, Leamington Spa, 1974.
Published by The Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.



* C L M S *