

1197931

PATENT SPECIFICATION

DRAWINGS ATTACHED

1197931



Date of Application (No. 32803/67) and filing Complete Specification: 17 July, 1967.

Application made in United States of America (No. 575,399) on 26 Aug., 1966.

Complete Specification Published: 8 July, 1970.

Index at acceptance:—H4 D(G1G2, G3P, G3R, G4A5, G7P)

International Classification:—G 01 v 1/36

COMPLETE SPECIFICATION

NMO Correction of Digitized Seismic Signals

We, TEXAS INSTRUMENTS INCORPORATED, a Corporation organized according to the Laws of the State of Delaware, United States of America, of 13500 North Central Expressway, Dallas, Texas, 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 seismic exploration and more particularly to a precise correction for normal moveout (NMO) of digitized seismic data.

In seismic exploration, it is known to shift the relative time relationships between seismic events along a given seismic trace to correct for spread geometry. The correction ordinarily is made such that seismic events on the corrected trace will appear at a time corresponding with vertical travel paths rather than angular or curved travel paths which are inherent in seismic systems where detectors are spaced laterally from the shot location. Large corrections are necessary at early record times and relatively small corrections are required at late record times because during such late record times, the angular or curved travel paths come closer and closer to correspondence with vertical travel paths.

Where seismic records are to be digitized, seismic signals are generated in analog form to correspond with seismic waves detected at the earth's surface. Such analog signals are then sampled at uniform time intervals ΔT to provide discrete representations of the received waveform. As is well known, the relationships between input time and output time for normal moveout correction is:

where:

T_x is input time,

T_y is output time,

X is horizontal offset between shot and detector,

V is the average propagation velocity of the seismic energy from the shot through the subsurface material to the point of reflection and back to the detector.

In correcting digitized seismic data for selected time T_y , the amplitude of the input seismic trace at a time between the sample points is often required. Such amplitude data is not present on the digitized seismogram. Though such data is not available, it is desired that the corrected record faithfully represent the original seismic waves. The present invention is directed to correcting for NMO wherein the proper amplitude will be produced even though such data is not present on the input records.

The present invention provides a method of processing a digitized field seismic trace comprising: retrievably storing data words of the digitized field trace in the sequence in which they occur in the trace, successively selecting time domain interpolation filters, and applying the selected filters to retrieved words of the digitized field trace in dependence on successively located time points along the time scale between adjacent data words at which time points the trace amplitude is to be interpolated and in dependence on time variations in geometry of the travel paths of seismic waves represented by the digitized field trace to produce a digitized record seismic trace corrected for normal moveout.

The filters can be applied to successive data sets of the stored data words, each set comprising members corresponding in number to the number of elements in the filter applied thereto and with each point at which the trace is to be interpolated being located at a pre-

$$T_x = \sqrt{T_y^2 + \frac{X^2}{V^2}} \quad (1)$$

determined position in the sets. In one embodiment, the time points at which the filters are applied are uniformly spaced between adjacent data words in the digitized field trace and the application of the filters can be made in dependence on a linear segmented representation of the normal moveout time characteristic of the variations in the said geometry of the travel paths.

5 The invention also provides apparatus for processing a digitized field seismic trace comprising: means operable to retrievably store data words of the digitized field trace in the sequence in which they appear in the field trace, a plurality of time domain interpolation filters operable to interpolate the amplitude value of the digitized field trace at any one of a like plurality of time points in the time interval between successive data words in the field trace, and switching means operable in dependence upon time variations in geometry of the travel paths of seismic waves represented by the digitized field trace to apply the filters sequentially to respective successive data sets of stored data words, each set corresponding in number to the number of elements in the filter applied thereto and with each time point at which the trace is to be interpolated being located at a predetermined position in the sets of data words to produce a digitized record seismic trace corrected for normal moveout.

10 Further, the invention comprehends apparatus for processing a digitized field seismic trace to produce a digitized record seismic trace corrected for normal moveout which apparatus comprises storage registers for storing sequential data words from the digitized field trace which are representative or at least a selected segment of the field trace, a set of multi-element time domain trace-amplitude interpolation filters including one filter for each of a plurality of spaced apart time points spanning the time interval between a pair of adjacent data words in the digitized field trace, means operable to register the outputs of the filters, gating means operable to selectively control the flow of data words from the storage registers through the filters to the output register means, and means operable to energize the gating means to apply the filters one at a time to respective successive data sets of the data words in the order of increasing time on the digitized field trace and with each time point on the field trace corresponding with a corrected time point located centrally of the time segments spanned by a given set of the data words. The gating means preferably is operable to control flow of the data words in sets, the number of words per set corresponding with the number of elements in the filters and the storage registers can comprise a bank of registers operable to derive the data words from means

capable of cyclically reproducing the digitized field trace. 65

For a more complete understanding of the present invention, embodiments thereof will be described in greater detail with reference to the accompanying drawings in which: 70

Figure 1 illustrates a seismic short-spread geometry; 75

Figure 2 illustrates, by wiggle trace representation, normal moveout correction for reflections obtained in the system of Figure 1; 80

Figure 3 illustrates the relationships between uncorrected and corrected record times; 85

Figure 4 illustrates one embodiment of the present invention for correcting a digitized seismic trace for normal moveout; 90

Figure 5 is a time graph showing operation of gates of Figure 4; and 95

Figure 6 diagrammatically represents the filters of Figure 4. 100

Referring now to Figure 1, a seismic exploring system has been illustrated wherein an explosive charge 10 at a shot point 11 is detonated to produce seismic waves which travel downwardly for reflection from subsurface horizons. Waves traveling along paths 12 and 17 are reflected from the top of a bed 15. Waves traveling along paths 16 and 13 are reflected from the bottom of bed 15. The waves traveling along paths 12 and 16 are detected by a seismometer 20. Seismometer 20 together with seismometer 21—25 comprise a detector spread, the members of which are offset laterally along the earth's surface at successively greater distances from shot point 11. Seismic waves traveling along paths 13 and 17 are detected by the seismometer 25. 105

In practice, seismometers at twelve, twenty-four or more detecting stations will be employed. However, only six detectors have been shown in Figure 1 in order to illustrate the principles involved in the present invention. 110

The signals from the detectors are recorded in phonographically reproducible form as on a magnetic tape or belt on a drum 30. The seismic signals are processed before recording on drum 30 by a unit 31 which separately samples the signals from each of the detectors 20—25 at uniform time intervals ΔT following the instant of detonation of the charge 10. Signals are thus digitized and suitably multiplexed in accordance with known procedures such that there is stored on the drum 30 digitized representations of all of the seismic signals. 115

In Figure 2 trace 35 on a first record 36 has been illustrated in wiggle trace form to illustrate the corrections that are to be made in accordance with the present invention on each trace on the drum 30. On trace 35 a time break pulse 37 represents the time of detonation of charge 10. Following pulse 37, the trace is relatively quiet except for reflection 120 125

pulses 38 and 39. Pulse 38 may be considered to be the reflected energy traveling along path 12 from charge 10 to detector 20. The pulse 39 represents the reflection of energy traveling along path 16 to the bottom of bed 15 and back to detector 20.

Because of the lateral offset X of detector 20 from short 10, the times T_x and T_x , if

converted into depth by applying the known velocities of sound through the formations above and in bed 15, would give an erroneous interpretation of the actual depth and thickness of the bed 15. In order to accurately portray the depth and thickness of bed 15, it is necessary to shift both reflection pulses 38 and 39 non-linearly with time to account for the difference in angularity or geometry of the paths traversed by the reflection energy. A corrected trace 40 on a second seismogram 41 has been illustrated also in wiggle trace form in order to illustrate the non-linear correction involved in the present invention. It will be noted that the reflection 38a has been shifted in time more than the shift in time of the reflection 39a. The relative time shift is dependent upon the geometry of the paths 12 and 16, respectively, and velocity.

While analog systems heretofore have been employed for carrying out the non-linear time shift illustrated in Figure 2, a faithful correction of the seismic data when in digitized form has heretofore not been accomplished. In digitizing the seismic traces, as by unit 31, the data between the discrete time samples is discarded. However, when corrections are to be made for NMO, the amplitude data which has been discarded must be resurrected for at least one data point between adjacent time samples unless the shift in time for NMO at a given point on the record is an integral multiple of the digitized sampling interval ΔT . The latter coincidence in general occurs only infrequently. The method being described which embodies the present invention, is directed to the provision and use of a plurality of interpolation filters which will produce an output signal from a plurality of digitized input data points, which output signal is representative of one of the discarded values but having the value that the trace should have at a given sampling point in a trace corrected for NMO.

In Figure 3, the smooth curve 50 represents the relationship between the field record time T_x and the corrected record time T_v . The T_x - T_v relationship for a given field record is divided into a plurality of straight line segments 51-57 which approximate the curve 50. The curve 50 and the approximation therefor are determined by the distance X , Figure 1, for example, and the average velocity V for successively increasing record times T_v . Since the time function of a trace corrected

for NMO is to be digitally recorded at equally spaced increments of time T_v , normally it is necessary to interpolate for the value of the input signals at the corresponding T_x times given by Equation 1.

The interpolation in the system illustrated in Figure 4 is carried out by the use of selected ones of a set of six-point interpolation filters. This interpolation forms the basis of the embodiment of this invention being described.

The selection of the segments 51-57 of Figure 3 provides a coarse sample of the input-output time relationships expressed by Equation 1. It will be noted that the sample points on the approximate curve of Figure 3 do not exactly fall on curve 50. This is because the T_x times required by Equation 1 are rounded to the nearest output sample period. After sampling curve 50 at each of the points indicated in Figure 3, it is then assumed that the curve is linear at times intermediate to the samples. In effect, Equation 1 is approximated by a number of straight line segments.

As illustrated in Figure 4, the data on trace 35 recorded on drum 30 in digitized form is played back with the successive time samples being stored by way of channel 60 in a bank or storage registers 61. A timing trace 30b is stored on drum 30 to provide output pulses corresponding with the sampling intervals ΔT employed in digitizing the traces as in Figure 1. The digitized seismic data is thus stored in registers 61.

A portion of the storage system has been shown in Figure 4 in order to illustrate the invention. More particularly, the data for the record interval starting at 0.490 second will be employed to provide data words for the corrected record over the interval 0.400 to 0.480 second as follows. The data stored in registers 61 has been indicated in terms representative of record times 490 to 600. It will be understood that the data words actually stored in the registers 61 represent the amplitudes of the trace 35 at each of the successive record times 0.490, 0.492, 0.494, . . . 0.600 second. The data words thus stored are employed to produce a trace 65 on drum 64 which is accurately corrected for NMO by the use of a set 66 of interpolation filters. There are twenty filters F0-F19 in set 66. The filters are employed in an ordered sequence depending upon the requirements dictated by the NMO relationships.

More particularly, in Figure 4, it will be noted that registers 498 to 514 are connected by suitable signal channels to a multi-channel gate 70. The data words thus controlled by gate 70 are selectively transferred to nine channels 71-79. In a similar manner, the words stored in registers 510 to 526 are controlled by gate 80. The latter words are also selectively applied to channels 71-79, respectively. Similarly, the contents of registers 522-538 are applied by way of gate 81 to

the channels 71—79 respectively. Data words in registers 534—550 are applied by way of gate 82 to channels 71—79, respectively.

Channel 72 is connected by a data channel 90 to filter F0. Channels 71—76 are connected by channels 91 to filters F4. Channels 72—77 are connected by way of channels 92 to filter F8. Channels 73—78 are connected by way of channels 93 to filter F12. Channels 74—79 are connected by way of channels 94 to filter F16.

The outputs of filters F0—F16 are applied to AND gates, G0—G16 and thence to a common bus 95 which leads to a recording head 96 on drum 64. Gates 70, 80, 81, and

82, as well as AND gates G0—G16, are controlled by a counter 100 which is energized by timing pulses on channel 101 leading from timing trace 30b on drum 30. Drums 30 and 64 are synchronized. Such synchronization is illustrated by mounting both drums on the common shaft 102 with a common drive motor 103.

The filters F0, F4, F8, F12 and F16 are six-point time domain filters having the weights illustrated in Table I. The filters F0—F19 are provided for interpolations at any one of twenty points in the time interval $\Delta T = 0.002$ second.

TABLE I

Filter Weights

F0	T _x	F4	T _x	F8	T _x	F12	T _x	F16	T _x
0	496	.0124982	498	.0182352	500	.0169157	502	.00997308	504
0	498	-.0856764	500	-.116616	502	-.102322	504	-.0576166	506
1.0	500	.896375	502	.710283	504	.473948	506	.224727	508
0	502	.224727	504	.473948	506	.710283	508	.896375	510
0	504	-.0576166	506	-.102322	508	-.116616	510	-.0856764	512
0	506	.00997308	508	.0169157	510	.0183252	512	.0124982	514

Table II illustrates the relationship between the times T_v and T_x where it is desired to produce, from an input seismic record digitized at time intervals of 0.002 second, an output record corrected for NMO and having data points at 0.004 second intervals, wherein m refers to an input time summation index of the sample data points along the digitized seismic trace or record to be filtered.

TABLE II

Interpolation Filter Selection

$\bar{V} (T_v)$	T_v (ms)	T_x (ms)	m	Filter
5000'/sec.	0.400	0.5000	0	F0
	0.404	0.5024	1	F4
	0.408	0.5048	2	F8
	0.412	0.5072	3	F12
	0.416	0.5096	4	F16
	0.420	0.5120	5	F0
	0.424	0.5144	6	F4
	0.428	0.5168	7	F8
	0.432	0.5192	8	F12
	0.436	0.5216	9	F16
	0.440	0.5240	10	F0
	0.444	0.5264	11	F4
	0.448	0.5288	12	F8
	0.452	0.5312	13	F12
	0.456	0.5336	14	F16
	0.460	0.5360	15	F0
	0.464	0.5384	16	F4
	0.468	0.5408	17	F8
	0.472	0.5432	18	F12
	0.476	0.5456	19	F16
5685'/sec.	0.480	0.5480	0	F0

From the column T_x of Table II, it will be noted that time spacings between digitized data points reoccur cyclically so that only filters F0, F4, F8, F12, and F16 are required for correcting the record for NMO over the output record interval 0.400 second to 0.480 second. It will be noted from Table II that no interpolation is necessary on filter F0 but that interpolation by suitably weighing the elements of the six-point time domain filter for each of filters F4, F8, F12, and F16 is required. Thus, filters F0, F4, F8, F12, and F16 will have the weights indicated in Table I. From Table I, it will be noted that the filter selected for interpolation of a given output value has two center elements which fall on opposite sides of the time T_x on the input seismogram at which data for the corrected record is required. From Table II, the digitized value of the corrected record at time 0.404 second is the value of the input record at time $T_x = 0.5024$ second. The last column of Table II indicates that filter F4 is to be employed to interpolate the value of the input record in such intermediate record time. From Table I, it will be seen that filter F4 has six elements uniformly divided on either side of the data point 0.5024 second.

The same is true of each of filters F8, F12, and F16 for interpolating the values required at output record time 0.408, 0.412, and 0.416 second, respectively.

Figure 5 illustrates the timing sequence of gates 70 and 80—82 and gates G0—G16 for correction in the output record over the time interval 0.400 to 0.480 second.

In Figure 5, the function 110 represents the timing track 30b, Figure 4. The function

111 represents the control of gate 70 with gate 70 being opened during an interval which coincides with pulses 0.400 to 0.416. In a similar manner, the functions 112, 113, and 114 illustrate control of gates 80—82, respectively, with opening being sequential and at the times indicated in Figure 5. Functions 120—139 represent the control of gates G0—G19. Gates G0, G4, G8, G12, and G16 are opened sequentially and cyclically at the times and in the order illustrated on functions 120, 124, 128, 132, and 136.

In Figure 6, filter F0 and filter F4 have been plotted. Filter F0 merely has one effective element of unity weight. However, filter F4 has the filter element a1 of weight 0.01249817. Element a2 has a weight of -0.08567637. Element a3 has a weight of 0.8963751. Element a4 has a weight of 0.2247272. Element a5 has a weight of -0.05761655. Element a6 has a weight of 0.009973082.

Thus, the filters are time domain interpolation operators which may be in analog form, in which case the units F0—F16 would each include input digital - to - analog converters. Alternatively, they may be of digital form wherein each digital word is multiplied by a weighting factor from the selected filter and the several products are summed to produce at the output the values indicated in Table II.

In correcting the entire trace over the range indicated by Figure 3, twenty filters F0—F19 will all be used. The filters will have the construction indicated in Table III where the weights of elements a1—a6 of filters F0—F10 are read from Table III right to left, and where the weights of filters F10—F19 are read from left to right.

TABLE III

Filter	a1	a2	a3	a4	a5	a6	Filter
	→ 0	0	0	1.0	0	0	F0
F19	.002607094	-.014624850	.051967000	.983275300	-.026814600	.003667171	F1
F18	.005172828	-.029290550	.107089200	.960191900	-.050010890	.006998006	F2
F17	.007644846	-.043715180	.164853500	.931097000	-.069613940	.009952532	F3
F16	.009973082	-.057616650	.224727200	.896375100	-.085676370	.012498170	F4
F15	.012109060	-.070710510	.286154600	.856452600	-.098281720	.014610940	F5
F14	.014006510	-.082712630	.348561000	.811793300	-.107542700	.016275210	F6
F13	.015622050	-.093341810	.411358100	.762894600	-.113599100	.017483320	F7
F12	.016915740	-.102322500	.473948400	.710283000	-.116616100	.018235240	F8
F11	.017851730	-.109387300	.535730000	.654509000	-.116781600	.018538130	F9
F10	.018402380	-.114292200	.596122400	.596122400	-.114292200	.018402380	F10
	a6	a5	a4	a3	a2	a1 ←	

The interval ΔT is divided into twenty segments and a filter is provided for each segment. Each separate filter is given weights in accordance with known interpolation filter theory. The filters are then selected as shown in Figure 4 such that the proper filter is applied to six points equally divided by the trace interval ΔT in which the desired value of the trace falls.

The seismogram to be corrected in accordance with the present invention may be produced in accordance with U.S. Patent No. 3,075,607 to Aitken et al. and U.S. Patent No. 3,074,636 to Baker et al., wherein the signals are digitized and multiplexed and recorded on a single recording medium such as a recording tape. As described in said Baker et al. patent, the data on the tape may be accompanied by a clock track and block marker track. The clock track may correspond with the trace 30b of Figure 4. The trace 35 of Figure 4 represents a single seismic trace that has not been multiplexed, although a trace recorded in multiplexed form with other traces may be demultiplexed and the time spaced samples thereof stored in register 61 for correction in accordance with the present invention.

While gates 70 and 80—82 have been illustrated as single units, it is to be understood that each of the registers 61 will be a multi-bit register and that each channel leading from such registers will be such as commonly employed in the art for transferring in parallel all of the bits stored in a register. Thus, the channels 71—79 will be provided for parallel transfer from gates 70 and 80—82 to filters 66. Similarly, the output channels from the filters 66 and the gates (or shift registers) G0—G16 will be provided for parallel transfer. In accordance with U.S. Patent No. 3,074,636, each data sample from the seismogram would be represented by a digital word of eighteen data bits. Thus, the registers, gates, channels, and filters of Figure 4 in completely digital form preferably will accommodate seismic traces thus digitized.

The foregoing description has been limited to correction of a short segment of trace 35. It will be understood, however, that data words corresponding with the entire seismogram may be successively stored in blocks and interpolation carried out on the stored data words by filters F0—F19. In each such case the filters would be selectively applied to the data words in dependence upon the T_x and T_v relationships illustrated in Figure 3. If desired, the interpolation operation for NMO correction may be carried out automatically by use of a digital computer wherein the filters F0—F19 are stored in such computer and the data words are sequentially applied to such filter under the control of a suitable program. Depending

upon the slope of the particular segment of the T_x — T_v characteristic plotted in Figure 3, which is applicable to a given record segment, different groups of the filters would be selected rather than the limited group of F0, F4, F8, F12 and F16 upon which the above description is based.

In order to achieve the high fidelity desired in the interpolation, certain precautions must be taken in setting up the basic I—O map of Figure 3 in order to insure that an interpolation filter exists for the exact T_x time to be interpolated. For example, in a basic table comprising a column of output T_v times and a column of corresponding input T_x times determined from Equation (1), the T_v increment in such a basic table may remain unspecified but the number of output points (hence the number of interpolations) between adjacent T_v values in the table is:

$$\frac{T_{v_{i+1}} - T_{v_i}}{\Delta T_o} \quad (2)$$

where ΔT_o is the sample period in milliseconds at which the output time function is to be generated. The ratio

$$R = \frac{T_{x_{i+1}} - T_{x_i}}{T_{v_{i+1}} - T_{v_i}} \quad (3)$$

is the slope of the straight line segments approximating the T_x , T_v curve between the two adjacent points in the basic table. Since move-out is assumed to be linear between these two points, the input time function must be evaluated at every $R\Delta T_o$ increment of time. In order to insure a filter exists for each of these T_x increments of time, it is necessary that

$$R(NF) = C, \text{ an integer} \quad (4)$$

where

NF = number of available filters.

The minimum number of filters necessary is

$$NF = \frac{T_{v_{i+1}} - T_{v_i}}{\Delta T_o} \quad (5)$$

Thus, in order to employ a minimum num-

ber of filters, Equation (4) implies the additional restriction

(6)

$$\left(\frac{T_{x_{i+1}} - T_{x_i}}{T_{y_{i+1}} - T_{y_i}} \right) \left(\frac{T_{y_{i+1}} - T_{y_i}}{\Delta T_o} \right) = C$$

or

$$T_{x_{i+1}} - T_{x_i} = C \Delta T_o$$

which says the values in the T_x column of the basic table must be rounded to the nearest output sample period. As above noted, this is the reason the X's in Figure 3 do not lie exactly on the curve.

In a practical sense for computer operations, R must in general be restricted to some minimum value. This restriction may be imposed by computer limitations and/or running time considerations. This restriction implies that normal movement corrections cannot be

applied until such time when R has a value in excess of its minimum. This forms the basis for specifying the T_y increment in the basic I—O map and the minimum number of interpolation filters needed. From Equations (4) and (5) it is determined that:

20

$$T_{y_{i+1}} - T_{y_i} = \frac{\Delta T_o C}{R_{\min}} \quad (7)$$

and C must be chosen divisible by $R_{\min}$ because the T_y increment must be an integral multiple of the output sample period ΔT_o . Thus, the choice of C establishes the T_y increment in the basic I—O map and the minimum number of filters necessary to insure one exists for every output time interpolated for. If the filters are identified FO through F(N—1), where N is the total number of filters, the output times intermediate to those in the basic table, the corresponding input times and the appropriate filter for each can be determined from the following equations:

25

30

35

$$\text{output time } t_{y_n} = T_{y_i} + n \Delta T_o$$

$$\text{input time } t_{x_n} = T_{x_i} + n \Delta T_o R$$

$$\text{filter number} = [n(R) \left(\frac{\Delta T_o}{\Delta t_i} \right) \text{ NF}] \text{ modulo NF}$$

(8)

n=0, 1, 2, . . . N—1

where:

Δt_o = corrected trace data interval, and
 Δt_i = field trace data sample interval.

The interpolation filters are six points in length and are designed to interpolate to a very high degree of accuracy. After the input time to be interpolated for and the appropriate filter have been determined and as indicated by Equation (8) above, the filter is drawn from its storage location in core and applied to the appropriate points in the input time function.

Where an input time function has been recorded digitally at equal increments of time ΔT , it must be interpolated for at time t_{x_n}

which lies between two recorded samples. The filter is applied to the three values either side of t_{x_n} to give

$$f(t_{x_n}) = \sum_{i=1}^6 a_i X_i$$

where:

$$f(t_{x_n}) = \text{value of the function at time } t_{x_n}$$

a_i = filter weights,

X_i = recorded values of the input time

function. The value $f(t_{x_n})$ is then stored or recorded at the corresponding output time dictated by Equation (8).

It will be appreciated that the method is not limited to the use of a six-point time domain filter. The number of filter elements will be selected in dependence upon the bandwidth and fidelity to be maintained in the cor-

65

rected seismic trace. However, six-point filters have been employed and found to provide a fidelity of 60—70 db over a bandwidth of from 0 to 100 cycles per second. The higher the fidelity and/or the wider the bandwidth, the longer the filter that will be required.

WHAT WE CLAIM IS:—

1. A method of processing a digitized field seismic trace comprising: retrievably storing data words of the digitized field trace in the sequence in which they occur in the trace, successively selecting time domain interpolation filters, and applying the selected filters to retrieved words of the digitized field trace in dependence on successively located time points along the time scale between adjacent data words at which time points the trace amplitude is to be interpolated and in dependence on time variations in geometry of the travel paths of seismic waves represented by the digitized field trace to produce a digitized record seismic trace corrected for normal moveout.

2. A method according to Claim 1, in which the filters are selected and applied in dependence on successively located time points along the said time scale and in dependence on the average propagation velocity through the subsurface material of the seismic energy resulting from the seismic disturbance giving rise to the digitized field trace.

3. A method according to Claim 1, in which the filters are applied to respective successive data sets of the stored data words, each set comprising members corresponding in number to the number of elements in the filter applied thereto and with each time point at which the trace is to be interpolated being located at a predetermined position in the sets.

4. A method according to Claim 3, in which the filters are applied in dependence on a linear segmented representation of the normal moveout time characteristic of the variations in the said geometry of the travel paths.

5. A method according to Claim 3 or Claim 4, in which the time points at which the filters are applied are uniformly spaced between adjacent data words in the digitized field trace.

6. A method according to Claim 3 or Claim 4, in which each time point at which a filter is applied corresponds with a corrected time point located centrally of the time segments spanned by a given set of the data words.

7. A method according to Claim 1, substantially as described herein with reference to the accompanying drawings.

8. Apparatus for processing a digitized field seismic trace comprising: means operable to retrievably store data words of the digitized field trace in the sequence in which they appear in the field trace, a plurality of time domain interpolation filters operable to interpolate the amplitude value of the digitized field trace at any one of a like plurality of time point in the time interval between suc-

cessive data words in the field trace, and switching means operable in dependence upon time variations in geometry of the travel paths of seismic waves represented by the digitized field trace to apply the filters sequentially to respective successive data sets of stored data words, each set corresponding in number to the number of elements in the filter applied thereto and with each time point at which the trace is to be interpolated being located at a predetermined position in the sets of data words, to produce a digitized record seismic trace corrected for normal moveout.

9. Apparatus according to Claim 8, including means to operate the switching means in dependence on a straight line segmented representation of the normal moveout time characteristic of the variations in geometry of the said travel paths.

10. Apparatus according to Claim 8, including means to operate the switching means to apply sets of the said data words to the filters, with each time point at which the digitized field trace is to be interpolated being located in the time segment between the central members of each set.

11. Apparatus for processing a digitized field seismic trace to produce a digitized record seismic trace corrected for normal moveout, said apparatus comprising

storage registers for storing sequential data words from the digitized field trace which are representative of at least a selected segment of the field trace, a set of multi-element time domain trace-amplitude interpolation filters including one filter for each of a plurality of spaced apart time points spanning the time interval between a pair of adjacent data words in the digitized field trace, means operable to register the outputs of the filters, gating means operable to selectively control the flow of data words from the storage registers through the filters to the output register means and means operable to energize the gating means to apply the filters one at a time to respective successive data sets of the data words in the order of increasing time on the digitized field trace and with each time point on the field trace corresponding with a corrected time point located centrally of the time segments spanned by a given set of the data words.

12. Apparatus according to Claim 11, in which the gating means is operable to control flow of the data words in sets, the number of words per set corresponding with the number of elements in the filters.

13. Apparatus according to Claim 11 or Claim 12, in which the storage registers comprise a bank of registers operable to derive the data words from means capable of cyclically reproducing the digitized field trace.

14. Apparatus according to any one of Claims 11—13, in which the time domain filters are applied to interpolate the digitized

70

75

80

85

90

95

100

105

110

115

120

125

130

rected seismic trace. However, six-point filters have been employed and found to provide a fidelity of 60—70 db over a bandwidth of from 0 to 100 cycles per second. The higher the fidelity and/or the wider the bandwidth, the longer the filter that will be required.

WHAT WE CLAIM IS:—

1. A method of processing a digitised field seismic trace comprising: retrievably storing data words of the digitized field trace in the sequence in which they occur in the trace, successively selecting time domain interpolation filters, and applying the selected filters to retrieved words of the digitized field trace in dependence on successively located time points along the time scale between adjacent data words at which time points the trace amplitude is to be interpolated and in dependence on time variations in geometry of the travel paths of seismic waves represented by the digitized field trace to produce a digitized record seismic trace corrected for normal moveout.

2. A method according to Claim 1, in which the filters are selected and applied in dependence on successively located time points along the said time scale and in dependence on the average propagation velocity through the subsurface material of the seismic energy resulting from the seismic disturbance giving rise to the digitized field trace.

3. A method according to Claim 1, in which the filters are applied to respective successive data sets of the stored data words, each set comprising members corresponding in number to the number of elements in the filter applied thereto and with each time point at which the trace is to be interpolated being located at a predetermined position in the sets.

4. A method according to Claim 3, in which the filters are applied in dependence on a linear segmented representation of the normal moveout time characteristic of the variations in the said geometry of the travel paths.

5. A method according to Claim 3 or Claim 4, in which the time points at which the filters are applied are uniformly spaced between adjacent data words in the digitized field trace.

6. A method according to Claim 3 or Claim 4, in which each time point at which a filter is applied corresponds with a corrected time point located centrally of the time segments spanned by a given set of the data words.

7. A method according to Claim 1, substantially as described herein with reference to the accompanying drawings.

8. Apparatus for processing a digitized field seismic trace comprising: means operable to retrievably store data words of the digitized held trace in the sequence in which they appear in the field trace, a plurality of time domain interpolation filters operable to interpolate the amplitude value of the digitized field trace at any one of a like plurality of time point in the time interval between suc-

cessive data words in the field trace, and switching means operable in dependence upon time variations in geometry of the travel paths of seismic waves represented by the digitized field trace to apply the filters sequentially to respective successive data sets of stored data words, each set corresponding in number to the number of elements in the filter applied thereto and with each time point at which the trace is to be interpolated being located at a predetermined position in the sets of data words, to produce a digitized record seismic trace corrected for normal moveout.

9. Apparatus according to Claim 8, including means to operate the switching means in dependence on a straight line segmented representation of the normal moveout time characteristic of the variations in geometry of the said travel paths.

10. Apparatus according to Claim 8, including means to operate the switching means to apply sets of the said data words to the filters, with each time point at which the digitized field trace is to be interpolated being located in the time segment between the central members of each set.

11. Apparatus for processing a digitized field seismic trace to produce a digitized record seismic trace corrected for normal moveout, said apparatus comprising

storage registers for storing sequential data words from the digitized field trace which are representative of at least a selected segment of the field trace, a set of multi-element time domain trace-amplitude interpolation filters including one filter for each of a plurality of spaced apart time points spanning the time interval between a pair of adjacent data words in the digitized field trace, means operable to register the outputs of the filters, gating means operable to selectively control the flow of data words from the storage registers through the filters to the output register means and means operable to energize the gating means to apply the filters one at a time to respective successive data sets of the data words in the order of increasing time on the digitized field trace and with each time point on the field trace corresponding with a corrected time point located centrally of the time segments spanned by a given set of the data words.

12. Apparatus according to Claim 11, in which the gating means is operable to control flow of the data words in sets, the number of words per set corresponding with the number of elements in the filters.

13. Apparatus according to Claim 11 or Claim 12, in which the storage registers comprise a bank of registers operable to derive the data words from means capable of cyclically reproducing the digitized field trace.

14. Apparatus according to any one of Claims 11—13, in which the time domain filters are applied to interpolate the digitized



field trace at uniformly spaced time points between a pair of adjacent data words in the field trace.

- 5 15. Apparatus for processing a digitized field seismic trace to produce a digitized record seismic trace corrected for normal moveout, substantially as described herein,

and arranged to operate in the manner described herein, with reference to and as illustrated by the accompanying drawings.

10

ABEL & IMRAY,
Chartered Patent Agents,
Quality House, Quality Court, Chancery Lane,
London, W.C.2.

Printed for Her Majesty's Stationery Office by the Courier Press, Leamington Spa, 1970.
Published by the Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from
which copies may be obtained.

