

Description

This invention relates to data processing and in particular to a method for correcting phase misalignment between sinusoidal waveforms.

5 As used herein, the term sinusoidal waveforms refers to waveforms which periodically pass through four states with respect to amplitude and slope. These states are positive amplitude with positive slope, positive amplitude with negative slope, negative amplitude with negative slope, and negative amplitude with positive slope. A perfect sinusoidal form is not required but, in general, a periodic movement through the four states described above will be present.

10 The invention is particularly applicable to waveforms encountered in seismic exploration which are referred to as sinusoidal wiggle traces. However, the invention is applicable to correcting phase misalignment between any set (2 or more) of sinusoidal waveforms.

For the sake of convenience, the invention will be described in terms of correcting phase misalignment for sinusoidal wiggle traces obtained in the mapping of geological subsurfaces. Such mapping involves the use of a source of seismic energy and its reception by an array of seismic detectors, generally referred to as geophones. When used on land, the source of seismic energy generally is a high explosive charge electrically detonated in a bore hole located at a selected grid point in a terrain or is an energy source capable of delivering a series of impacts to the earth's surface such as that used in Vibroseis®. The acoustic waves generated in the earth by the explosion or impacts are transmitted back from strata boundaries and reach the surface of the earth at varying intervals of time, depending on the distance and the nature of the subsurface traversed. These returning acoustic waves are detected by the geophones, which function to transduce such acoustic waves into representative electrical signals. The plurality of geophones are arrayed in a selected manner to detect most effectively the returning acoustic waves and generate electrical signals representative thereof from which data may be deduced concerning the geological subsurface of the earth.

25 The outputs from the seismic detectors are commonly summed to produce a composite trace for enhancing the subsurface structure information represented by features of such signals. The purpose of such summing is to give prominence to the important features in the seismic signal and to reduce or remove those features which obscure the important parts of the signal. Both direct and weighted summations of seismic detector array outputs have been used. Of particular importance in signal to noise enhancement are stacking techniques generally known in the art as common midpoint or common depth point stacking.

It is known that common midpoint stacking requires correction of the phase misalignment between the outputs from the seismic detectors which are to be summed. In the past, techniques such as crosscorrelation, which will be described more fully hereinafter, have been utilized to determine the amount of phase shift required to correct for phase misalignment. US 4 206 509 discloses a method for enhancing seismic reflection signals which includes crosscorrelating a portion of the traces falling within the same windows to determine time shifts and applying the time shifts to common depth point seismic traces. However, a large amount of computer time is required for processing techniques such as crosscorrelation and also, high amplitude, spurious noise may affect the accuracy of phase shifts determined by crosscorrelation.

40 It is also noted that many other data processing techniques associated with the processing of seismic data require correction for phase misalignment. It has been estimated that between 25% and 50% of the computer time spent in processing seismic data is spent in correcting phase misalignment which is a further indication of the need for faster and more accurate techniques for correcting phase misalignment.

45 It is thus an object of this invention to provide a method for correcting phase misalignment between sinusoidal waveforms such as sinusoidal wiggle traces obtained in seismic prospecting which takes less computer time than prior art techniques and is also accurate even if high amplitude, spurious noise is present in the sinusoidal waveforms.

In accordance with the present invention, a method for determining phase misalignment is provided as defined in claim 1. The amplitude of a plurality of sinusoidal-like waveforms is sampled at a desired sampling rate. The thus sampled amplitude is assigned a 2 bit quadrant value which indicates the state of the amplitude (positive or negative) and the slope of the sinusoidal-like signal at the particular data point sampled (positive or negative). Windows containing the data points over the same time interval are then selected.

50 Once the amplitude data has been assigned 2 bit quadrant values in said windows, the 2 bit values are shifted with respect to each other and tested for equality against each other. Multiple tests for multiple shifts are performed. It has been found that phase alignment occurs when the maximum number of matches between the 2 bit values for the data points of the plurality of sinusoidal waveforms occurs.

Other objects and advantages of the invention will be apparent from the foregoing brief description of the invention and the claims as well as the detailed description of the drawings which are briefly described as follows:

FIGURE 1 is an illustration of a typical seismic exploration system;

FIGURE 2 is an illustration of the waveforms which might be received from the seismic exploration system illustrated in FIGURE 1;

FIGURE 3 is an illustration of quadrant assignment; and

FIGURES 4 and 5 are illustrations of a comparison of correction of phase misalignment in accordance with the present invention to correction of phase misalignment by crosscorrelation.

Referring now to FIGURE 1, there is illustrated a plurality of seismic sources 21-25 and a plurality of seismic receivers 31-35 arranged around a common midpoint (CMP). For the sake of illustration, the seismic sources are equidistantly spaced and the seismic receivers are equidistantly spaced but this is not required and typically would not occur in seismic prospecting because of obstructions and other factors. However, each source receiver pair should be equally spaced from the common midpoint to the extent possible. Assuming a reflecting plane 37 which is substantially parallel to the surface on which the sources and receivers are located, acoustic waves from each of the seismic sources is reflected from the common depth point (CDP) and received by a respective one of the seismic receivers as is illustrated. The output from the seismic receivers 31-35 might be as illustrated in FIGURE 2.

The waveforms in FIGURE 2, which are illustrated as R_{31} - R_{35} , are out of phase because of the difference in travel time from the various sources to the various receivers as illustrated in FIGURE 1. It is necessary to correct this phase misalignment in order to obtain an optimum summation.

The steps utilized to correct phase misalignment for the sinusoidal wiggle traces illustrated in FIGURE 2 in accordance with the present invention are as follows.

1. SELECT PLURALITY OF DATA POINTS

A sinusoidal wiggle trace obtained in reflection seismology, such as illustrated in FIGURE 2, typically has a length in the range of about 4 seconds to about 8 seconds. A 6-second length is typical.

The amount of phase shift required-generally varies over the length of the sinusoidal wiggle trace. More phase shift is generally required for alignment at early time periods for the sinusoidal wiggle trace and less phase shift is generally required for later times.

Any suitable data sample rate may be utilized. However, again, the data sample rate should be such as to provide sufficient data points in a window to provide meaningful statistics. In this step, a plurality of data points is selected in a first part of the waveforms to be investigated. This first part of the waveforms is associated with a time window in step 3. It is believed that about 25 data samples in a window is a minimum for meaningful statistics and thus the sample rate for a 50 millisecond window should be 2 milliseconds or less and the sample rate for a 100 millisecond window should be 4 milliseconds or less. A 4 millisecond sample rate is typical even if windows longer than 100 milliseconds are selected.

It is noted that as another embodiment it is often convenient to select the data sample rate and window length (step 3, below) at the same time.

2. QUADRANT ASSIGNMENT

Once a data sample rate has been established, a quadrant assignment is made for each data point in a waveform based on amplitude and slope. For the sake of illustration, this process will be discussed in terms of only two signals but the process is applicable to determining a desired phase alignment for many waveforms.

Considering for the sake of illustration waveforms R_{31} and R_{32} illustrated in FIGURE 2, a quadrant assignment will be made for all data points for waveforms R_{31} and R_{32} . This quadrant assignment may be as illustrated in FIGURE 3 where a data point having a positive amplitude and a positive slope is assigned to quadrant zero and given a zero value, a data point having a positive amplitude and a negative slope is assigned to quadrant 1 and given a one value, a data point having a negative amplitude and a negative slope is assigned to quadrant 2 and given a two value and a data point having a negative amplitude and positive slope is assigned to quadrant 3 and given a three value.

It is noted that amplitude data will typically be in a 16 or 32 bit format. Conversion to a 2 bit equivalent (00, 01, 10, 11) is a particularly important aspect of the present invention with respect to saving computer

time as will be described more fully hereinafter.

Equations which can be utilized to make a quadrant assignment to the data points of waveforms R_{31} and R_{32} are as follows. The data point is assumed to be data point 1.

- If $A_1 \geq 0$ and $(A_1 - A_0) \geq 0$ then $Q_1 = 0$
 5 If $A_1 \geq 0$ and $(A_1 - A_0) < 0$ then $Q_1 = 1$
 If $A_1 < 0$ and $(A_1 - A_0) < 0$ then $Q_1 = 2$
 If $A_1 < 0$ and $(A_1 - A_0) \geq 0$ then $Q_1 = 3$

where

- 10 A_1 = amplitude of data point 1 (16 or 32 bit)
 A_0 = amplitude of the previous data point (16 or 32 bit)
 Q_1 = quadrant assignment of data point 1 (2 bit)

It is noted that the quadrant assignments for the data points are made on that part of the waveforms specified in step 1. Then the following steps are accomplished for that particular part. However, it is
 15 generally possible as an alternative to make a quadrant assignment for all data points at the same time.

3. ASSIGN WINDOW TIMES

20 To accommodate the variance in phase shift mentioned in step 1, the sinusoidal wiggle traces, such as illustrated in FIGURE 2, are preferably divided into windows or multiple sections having the same time intervals as the parts of the waveforms of step 1. Any desired window length may be utilized but the window length should be sufficient to provide meaningful statistics. In general, the window length should be in the range of about 50 milliseconds to about 200 milliseconds. An average window length is about 100
 25 milliseconds. For a 100 millisecond window length, a sinusoidal wiggle trace having a 6-second duration would be divided into 60 increments or windows.

Windows are assigned to the waveforms to be aligned. As an example, for a 100 millisecond window length, windows might be assigned from time zero. The first window for all waveforms would be from time zero to 100 milliseconds and the second from 100 milliseconds to 200 milliseconds. Windows are assigned
 30 to all desired portions of the waveforms.

4. WAVEFORM SHIFT

35 Using two signals again for the sake of illustration, one waveform is preferably shifted with respect to the other by a desired phase shift. This phase shift is preferably some multiple of the data sampling rate. As an example, waveform R_{32} might be shifted with respect to waveform R_{31} by 4 milliseconds or in other terms, 1 data point position either left or right. The first shift is referred to as phase shift position 1. Additional shifts are referred to by higher numbers and can start at the maximum phase shift position in one
 40 direction and move in the opposite direction so as to eliminate the need to specify shift direction.

5. BIT COMPARISON

45 After the desired phase shift is made, the value assigned to data point 1 of window 1 of waveform R_{31} is compared to the value assigned for data point 1 of window 1 of waveform R_{32} . Assuming 25 data points in window 1, this process is continued until data point 25 in window 1 for waveform R_{31} is compared to data point 25 in window 1 of waveform R_{32} . Window 1 for waveform R_{31} is over the same time interval as window 1 for waveform R_{32} .

50 If the quadrant value assigned to data point 1 of waveform R_{31} is equal to the quadrant value assigned to data point 1 of waveform R_{32} , then a value of 1 is added to a correlation total. This process is continued for all comparisons between data points until a final correlation total for window 1 is reached after the comparison of data point 25 for waveform R_{31} to data point 25 for waveform R_{32} .

An appropriate equation in BASIC computer language code which may be utilized for the bit
 55 comparison and the determination of a correlation total is as follows:

$$\text{SUM}(1) = \text{SUM}(1) - (Q1(1) - Q2(1))$$

where

- SUM(1) = correlation total for shift position #1
- Q1(1) = 2 bit quadrant value for data point #1 of waveform R₃₁
- 5 Q2(1) = 2 bit quadrant value for data point #1 of waveform R₃₂
- (Q1(1) = Q2(1)) is a bit mode equality statement which yields a 0 value if Q1(1) and Q2(1) are not equal, or else yields a -1 value if the left and right variables are equal.

10 6. REPEAT STEPS 4-5

After a correlation total for shift position 1 is determined, waveforms R₃₁ and R₃₂ are again shifted with respect to each other as in step 4. Step 5 is then repeated. This process is continued until a correlation total has been derived for all desired phase shifts for window 1. A BASIC computer language code which
15 could be utilized to accomplish steps 4 and 5 for all desired phase shifts for window 1 is as follows.

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FOR K = FL to LL
FOR J = FD to LD
20 SUM(K) = SUM(K) - (Q1(J) = Q2(J+K))
NEXT J
NEXT K

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where

- FL = first positional shift for window 1
- LL = last positional shift for window 1
- FD = first data position for correlation
- 30 LD = last data position for correlation
- SUM = correlation total

7. SELECT HIGHEST CORRELATION TOTAL FOR WINDOW 1

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The highest correlation total for window 1 is determined after all correlation totals have been derived. The phase shift which resulted in this highest correlation total is then noted. It has been found that this phase shift will result in an optimum phase alignment of waveforms R₃₁ and R₃₂ for window 1.

In a further embodiment of the invention, the above steps are repeated for additional windows.

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8. REPEAT STEPS 4-7 FOR ADDITIONAL WINDOWS

After correlation totals for window 1 are established for all desired phase shifts, correlation totals are
45 preferably established for all other windows for all desired phase shifts. The highest correlation total is then used to determine the desired phase shift for each window.

In another embodiment of the method, a correlation total could be established for all windows for phase shift 1 before additional phase shifts are made. Also, the bit comparison for all windows could be made before a correlation total is derived for each window.

50 A BASIC computer language code which could be used to accomplish steps 4-8 is as follows:

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FOR L = FW to LW
FOR K = FL to LL
FOR J = FD to LD
5  SUM (L,K) = SUM (L,K) - (Q1(J) = Q2(J+K))
NEXT J
NEXT K
10 NEXT L

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where

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FW          = first window
15  LW       = last window
FL,LL,FD,LD,SUM are as previously defined

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9. OUTPUT PHASE SHIFTS

The thus determined phase shifts are then output for use by other computer programs as desired. The output phase shifts can be utilized in common depth point stacking of waveforms R_{31} - R_{35} as previously described. Also, the phase shifts may be utilized in other applications such as corrections for changes in velocity of near service media which is generally referred to as weathering corrections.

EXAMPLES

The following examples are presented in further illustration of the invention. Since, in some of the examples, the correlation of the present invention will be compared to a conventional crosscorrelation, crosscorrelation will be briefly described hereinafter.

Crosscorrelation is a measure of the similarity of two sinusoidal waveforms. The objective of crosscorrelation is usually to quantify the amount of phase shift (time misalignment) between two waveforms as in the present invention. Crosscorrelation, which is well known to geophysicists, assumes that when the product of amplitudes of individual data points on two waveforms are maximized, the best correlation has been achieved.

Example 1

In FIGURE 4 there is illustrated two traces 1 and 2. The traces have been aligned so as to be in phase. In the lower portion of FIGURE 4, a comparison of crosscorrelation (XCOR) and quadrant correlation in accordance with the present invention (QCOR) is presented.

Point A is the percentage of matches obtained for the position of the traces illustrated in FIGURE 4. It can be seen that both a conventional crosscorrelation and quadrant correlation achieved a 100% match. Thus, both procedures result in an accurate phase alignment of traces 1 and 2 at this phase shift value.

For points B and C, trace 2 was phase shifted 1 data position to the right. This resulted in about 90% matches for crosscorrelation and 75% matches for quadrant correlation. Points to the right of points B and C of the XCOR and QCOR curves of FIGURE 4 represent further phase shifts to the right for trace 2. Points to the left of point A of the XCOR and QCOR curves represent shifts to the left for trace 2 with respect to trace 1. The horizontal axis of the graph are plotted as the phase shift between the traces.

As has been previously stated, amplitude data is typically in a 16 or 32 bit format. Crosscorrelation must utilize amplitudes and thus must work with these 16 or 32 bit formats. Thus, while crosscorrelation achieves the same results as quadrant correlation under the circumstances illustrated in FIGURE 4, a significant saving in computer time was realized because quadrant correlation requires only 2 bits of data for each data point. In addition, simple computer processes (bit equality tests) were used in place of more complex processes such as multiplication. For quadrant correlation in accordance with the present invention, computer computation time may be decreased on the order of 1/2 to 1/100 of computation time

required for crosscorrelation depending upon the data volume and the computer hardware and software. This savings in computer time is extremely significant when it is realized, as has been previously stated, that generally 25% to 50% of computer time utilized in processing seismic data is utilized in phase alignment.

- 5 Another advantage of quadrant correlation with respect to crosscorrelation is the more abrupt decay from a peak value in the quadrant correlation curve illustrated in FIGURE 4 as opposed to the crosscorrelation curve (point C is significantly below point B). This more abrupt decay is desirable because the peak correlation value which represents optimum phase shift is more uniquely defined for quadrant correlation and is less sensitive to spurious amplitude noise as will be more fully illustrated in Example 2.

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Example 2

- 15 Traces 1 and 2 from FIGURE 4 are again illustrated in FIGURE 5. However, trace 2 has been distorted by noise at point A. A quadrant correlation curve and crosscorrelation curve are again illustrated in FIGURE 5. For the quadrant correlation curve, the highest number of matches occurred for the alignment illustrated in FIGURE 5. However, for the crosscorrelation curve, the highest value occurred when trace 2 was shifted one position to the left at B. Thus, crosscorrelation would result in a less accurate phase alignment.

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Claims

1. A method for determining the phase misalignment between two or more periodic waveforms of sinusoidal-like form, said method comprising the steps of:
- 25 (a) selecting a plurality of data points in a first part of a first sinusoidal-like waveform and a first part of a second sinusoidal-like waveform, wherein said data points are equally spaced apart;
- 30 (b) assigning a quadrant value to each data point selected in step (a) for said first waveform and said second waveform depending on the position of the data point on the waveform, wherein a first quadrant value is assigned to a data point for a position with a positive amplitude and a positive slope, wherein a second quadrant value is assigned for a position with a positive amplitude and a negative slope, wherein a third quadrant value is assigned for a position with a negative amplitude and a negative slope and wherein a fourth quadrant value is assigned for a position with a negative amplitude and a positive slope, and wherein said values are converted to 2-bit equivalent quadrant values;
- 35 (c) selecting a respective first window over the same time interval for said first parts of said first and second waveforms, wherein said windows contain said plurality of the data points selected in step (a);
- 40 (d) shifting said second waveform with respect to said first waveform by a first phase shift;
- (e) comparing the 2-bit quadrant value assigned to the first data point in said first window for said first waveform to the 2-bit quadrant value assigned to the first data point in said first window for said second waveform shifted by said first phase shift to establish a first correlation value, wherein said first correlation value has a first value if the compared quadrant values are equal and has a second value if the compared quadrant values are not equal;
- 45 (f) repeating step (e) for all data points contained in said first window for said first waveform and said second waveform shifted by said first phase shift, wherein each data point in said first waveform is compared to a corresponding data point in said second waveform;
- (g) summing all correlation values established in steps (e) and (f) to establish a total correlation value for said first window for said first phase shift;
- 50 (h) repeating steps (d)-(g), wherein different phase shifts are applied in step (d) and wherein the total correlation values derived for each phase shift gives the phase misalignment between said first waveform and said second waveform in said first window.
2. A method in accordance with claim 1 additionally comprising the step of repeating steps (c)-(h), wherein second and subsequent windows are assigned in step (c) to different parts of said first waveform and said second waveform and wherein the repetition of steps (c)-(h) for different windows results in the determination of the phase misalignment between said first and second waveforms for each window assigned to different parts of said waveforms.

required for crosscorrelation depending upon the data volume and the computer hardware and software. This savings in computer time is extremely significant when it is realized, as has been previously stated, that generally 25% to 50% of computer time utilized in processing seismic data is utilized in phase alignment.

- 5 Another advantage of quadrant correlation with respect to crosscorrelation is the more abrupt decay from a peak value in the quadrant correlation curve illustrated in FIGURE 4 as opposed to the crosscorrelation curve (point C is significantly below point B). This more abrupt decay is desirable because the peak correlation value which represents optimum phase shift is more uniquely defined for quadrant correlation and is less sensitive to spurious amplitude noise as will be more fully illustrated in Example 2.

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Example 2

- 15 Traces 1 and 2 from FIGURE 4 are again illustrated in FIGURE 5. However, trace 2 has been distorted by noise at point A. A quadrant correlation curve and crosscorrelation curve are again illustrated in FIGURE 5. For the quadrant correlation curve, the highest number of matches occurred for the alignment illustrated in FIGURE 5. However, for the crosscorrelation curve, the highest value occurred when trace 2 was shifted one position to the left at B. Thus, crosscorrelation would result in a less accurate phase alignment.

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Claims

1. A method for determining the phase misalignment between two or more periodic waveforms of sinusoidal-like form, said method comprising the steps of:
 - 25 (a) selecting a plurality of data points in a first part of a first sinusoidal-like waveform and a first part of a second sinusoidal-like waveform, wherein said data points are equally spaced apart;
 - (b) assigning a quadrant value to each data point selected in step (a) for said first waveform and said second waveform depending on the position of the data point on the waveform, wherein a first quadrant value is assigned to a data point for a position with a positive amplitude and a positive slope, wherein a second quadrant value is assigned for a position with a positive amplitude and a negative slope, wherein a third quadrant value is assigned for a position with a negative amplitude and a negative slope and wherein a fourth quadrant value is assigned for a position with a negative amplitude and a positive slope, and wherein said values are converted to 2-bit equivalent quadrant values;
 - 30 (c) selecting a respective first window over the same time interval for said first parts of said first and second waveforms, wherein said windows contain said plurality of the data points selected in step (a);
 - (d) shifting said second waveform with respect to said first waveform by a first phase shift;
 - 40 (e) comparing the 2-bit quadrant value assigned to the first data point in said first window for said first waveform to the 2-bit quadrant value assigned to the first data point in said first window for said second waveform shifted by said first phase shift to establish a first correlation value, wherein said first correlation value has a first value if the compared quadrant values are equal and has a second value if the compared quadrant values are not equal;
 - 45 (f) repeating step (e) for all data points contained in said first window for said first waveform and said second waveform shifted by said first phase shift, wherein each data point in said first waveform is compared to a corresponding data point in said second waveform;
 - (g) summing all correlation values established in steps (e) and (f) to establish a total correlation value for said first window for said first phase shift;
 - 50 (h) repeating steps (d)-(g), wherein different phase shifts are applied in step (d) and wherein the total correlation values derived for each phase shift gives the phase misalignment between said first waveform and said second waveform in said first window.
2. A method in accordance with claim 1 additionally comprising the step of repeating steps (c)-(h), wherein second and subsequent windows are assigned in step (c) to different parts of said first waveform and said second waveform and wherein the repetition of steps (c)-(h) for different windows results in the determination of the phase misalignment between said first and second waveforms for each window assigned to different parts of said waveforms.

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3. A method in accordance with claim 2 wherein the phase misalignment between all of said first waveform and all of said second waveform is determined.
4. A method in accordance with claim 3 wherein said first waveform and said second waveform are sinusoidal-like wiggle traces.
5. A method in accordance with claim 1 wherein said first windows have a time length in the range of about 50 milliseconds to about 200 milliseconds and wherein at least 25 data points are contained in said first window.
6. A method in accordance with claim 5 wherein said first windows have a time length of about 100 milliseconds.
7. A method in accordance with claim 6 wherein said first quadrant value is 00, wherein said second quadrant value is 01, wherein said third quadrant value is 10 and wherein said fourth quadrant value is 11.
8. A method in accordance with claim 1 wherein the first value of said first correlation value is 1, wherein the second value of said first correlation value is 0.
9. A method according to claim 1 wherein the phase shift which results in the highest total correlation value is the phase misalignment between said first waveform and said second waveform in the given window, said phase shift representing the optimum shift for phase alignment of the waveforms.

Revendications

1. Procédé pour déterminer le déphasage entre deux formes d'onde périodique ou davantage de forme ressemblant à une sinusoïde, ledit procédé comprenant les étapes consistant à :
 - (a) sélectionner une multitude de points de donnée dans une première partie d'une première forme d'onde ressemblant à une sinusoïde et dans une première partie d'une seconde forme d'onde ressemblant à une sinusoïde, où lesdits points de donnée sont espacés de la même distance;
 - (b) affecter une valeur de quadrant à chaque point de donnée sélectionné dans l'étape (a) pour ladite première forme d'onde et ladite seconde forme d'onde en fonction de la position du point de donnée sur la forme d'onde, où une valeur de premier quadrant est affectée à un point de donnée pour une position avec une amplitude positive et une pente positive, où une valeur de second quadrant est affectée pour une position avec une amplitude positive et une pente négative, où une valeur de troisième quadrant est affectée pour une position avec une amplitude négative et une pente négative et où une valeur de quatrième quadrant est affectée pour une position avec une amplitude négative et une pente positive, et où lesdites valeurs sont converties en valeurs équivalentes de quadrant à 2 bits;
 - (c) sélectionner une première fenêtre respective sur le même intervalle de temps pour lesdites premières parties des première et seconde formes d'onde, où lesdites fenêtres contiennent ladite multitude des points de donnée sélectionnés dans l'étape (a);
 - (d) décaler ladite seconde forme d'onde par rapport à ladite première forme d'onde par un premier déphasage;
 - (e) comparer la valeur de quadrant à 2 bits affectée au premier point de donnée dans ladite première fenêtre pour ladite première forme d'onde à la valeur de quadrant à 2 bits affectée au premier point de donnée dans ladite première fenêtre pour ladite seconde forme d'onde décalée par ledit premier déphasage afin d'établir une première valeur de corrélation, où ladite première valeur de corrélation présente une première valeur si les valeurs de quadrant comparées sont égales et présente une seconde valeur si les valeurs de quadrant comparées ne sont pas égales;
 - (f) répéter l'étape (e) pour tous les points de donnée contenus dans ladite première fenêtre pour ladite première forme d'onde et ladite seconde forme d'onde décalée par ledit premier déphasage, où chaque point de donnée dans ladite première forme d'onde est comparé à un point de donnée correspondant dans ladite seconde forme d'onde;
 - (g) ajouter toutes les valeurs de corrélation établies dans les étapes (e) et (f) afin d'établir une valeur de corrélation totale pour ladite première fenêtre pour ledit premier déphasage;



(h) répéter les étapes (d)-(g), où des déphasages différents sont appliqués dans l'étape (d) et où les valeurs de corrélation totales obtenues pour chaque déphasage donnent le déphasage entre ladite première forme d'onde et ladite seconde forme d'onde dans ladite première fenêtre.

- 5 2. Procédé selon la revendication 1, comprenant en outre l'étape consistant à répéter les étapes (c)-(h), où une seconde fenêtre et des fenêtres ultérieures sont affectées dans l'étape (c) à des parties différentes de ladite première forme d'onde et de ladite seconde forme d'onde et où la répétition des étapes (c)-(h) pour différentes fenêtres se traduit par la détermination du déphasage entre les première et seconde formes d'onde pour chaque fenêtre affectée à des parties différentes desdites formes d'onde.
- 10 3. Procédé selon la revendication 2, dans lequel le déphasage entre la totalité de ladite première forme d'onde et la totalité de ladite seconde forme d'onde est déterminé.
- 15 4. Procédé selon la revendication 3, dans lequel ladite première forme d'onde et ladite seconde forme d'onde sont des traces agitées ressemblant à une sinusoïde.
5. Procédé selon la revendication 1, dans lequel lesdites premières fenêtres ont une durée dans la gamme allant d'environ 50 millisecondes à environ 200 millisecondes et où au moins 25 points de donnée sont contenus dans ladite première fenêtre.
- 20 6. Procédé selon la revendication 5, dans lequel lesdites premières fenêtres ont une durée d'environ 100 millisecondes.
- 25 7. Procédé selon la revendication 6, dans lequel ladite valeur du premier quadrant est 00, dans lequel ladite valeur du second quadrant est 01, dans lequel ladite valeur du troisième quadrant est 10 et dans lequel ladite valeur du quatrième quadrant est 11.
8. Procédé selon la revendication 1, dans lequel la première valeur de ladite première valeur de corrélation est 1, dans lequel la seconde valeur de ladite première valeur de corrélation est 0.
- 30 9. Procédé selon la revendication 1, dans lequel le déphasage qui résulte de la valeur totale de corrélation la plus élevée est le déphasage entre ladite première forme d'onde et ladite seconde forme d'onde dans la fenêtre donnée, ledit déphasage représentant le déphasage optimum des formes d'onde.

Ansprüche

1. Verfahren zur Bestimmung der Phasenabweichung zwischen zwei oder mehr periodischen Wellenformen von sinusartiger Form, wobei dieses Verfahren folgende Stufen umfasst:
 - (a) Auswahl einer Mehrzahl von Datenpunkten in einem ersten Teil einer ersten sinusartigen Wellenform und in einem ersten Teil einer zweiten sinusartigen Wellenform, wobei die Datenpunkte voneinander im gleichen Abstand angeordnet sind;
 - (b) Zuordnung eines Quadrantenwerts für jeden in Stufe (a) für die erste Wellenform und die zweite Wellenform ausgewählten Datenpunkt in Abhängigkeit von der Position des Datenpunkts auf der Wellenform, wobei ein erster Quadrantenwert einem Datenpunkt für eine Position mit einer positiven Amplitude und einer positiven Steigung, ein zweiter Quadrantenwert einem Datenpunkt für eine Position mit einer positiven Amplitude und einer negativen Steigung, ein dritter Quadrantenwert einem Datenpunkt für eine Position mit einer negativen Amplitude und einer negativen Steigung und ein vierter Quadrantenwert einem Datenpunkt für eine Position mit einer negativen Amplitude und einer positiven Steigung zugeordnet werden und wobei die Werte in äquivalente 2-Bit-Quadrantenwerte umgewandelt werden;
 - (c) Auswahl eines entsprechenden ersten Fensters über das gleiche Zeitintervall für die genannten ersten Teile der ersten und zweiten Wellenform, wobei die Fenster die Vielzahl der in Stufe (a) ausgewählten Datenpunkte enthalten;
 - (d) Verschiebung der zweiten Wellenform in Bezug zur ersten Wellenform um eine erste Phasenverschiebung;
 - (e) Vergleich des dem ersten Datenpunkt im ersten Fenster für die erste Wellenform zugeordneten



- 2-Bit-Quadrantenwerts mit dem dem ersten Datenpunkt im ersten Fenster für die zweite Wellenform nach Verschiebung um die erste Phasenverschiebung zugeordneten 2-Bit-Quadrantenwert, um einen ersten Korrelationswert zu ermitteln, wobei dieser erste Korrelationswert einen ersten Wert besitzt, wenn die verglichenen Quadrantenwerte gleich sind und einen zweiten Wert besitzt, wenn die verglichenen Quadrantenwerte nicht gleich sind;
- (f) Wiederholung der Stufe (e) für sämtliche Datenpunkte, die im ersten Fenster für die erste Wellenform und für die um die erste Phasenverschiebung verschobene zweite Wellenform enthalten sind, wobei die jeweiligen Datenpunkte in der ersten Wellenform mit einem entsprechenden Datenpunkt in der zweiten Wellenform verglichen werden;
- (g) Summenbildung sämtlicher in den Stufen (e) und (f) ermittelten Korrelationswerte zur Ermittlung eines Gesamtkorrelationswerts für das erste Fenster für die erste Phasenverschiebung; und
- (h) Wiederholung der Stufen (g) - (e), wobei unterschiedliche Phasenverschiebungen in der Stufe (d) angewandt werden und wobei die für die jeweiligen Phasenverschiebungen abgeleiteten Gesamtkorrelationswerte die Phasenabweichung zwischen der ersten Wellenform und der zweiten Wellenform im ersten Fenster ergeben.
2. Verfahren nach Anspruch 1, das zusätzlich die Stufe der Wiederholung der Stufen (c) - (h) erfasst, wobei das zweite und die folgenden Fenster in Stufe (c) unterschiedlichen Teilen der ersten Wellenform und der zweiten Wellenform zugeordnet werden und wobei die Wiederholung der Stufen (c)-(h) für unterschiedliche Fenster die Ermittlung der Phasenabweichung zwischen der ersten und zweiten Wellenform für jedes Fenster, das den unterschiedlichen Teilen der Wellenformen zugeordnet ist, ergibt.
 3. Verfahren nach Anspruch 2, wobei die Phasenabweichung zwischen der ersten Wellenform und der zweiten Wellenform ermittelt wird.
 4. Verfahren nach Anspruch 3, wobei es sich bei der ersten Wellenform und der zweiten Wellenform um sinusartige Schwebungsspuren handelt.
 5. Verfahren nach Anspruch 1, wobei die ersten Fenster eine Zeitdauer im Bereich von etwa 50 Millisekunden bis etwa 200 Millisekunden aufweisen und wobei im ersten Fenster mindestens 25 Datenpunkte enthalten sind.
 6. Verfahren nach Anspruch 5, wobei die ersten Fenster eine Zeitdauer von etwa 100 Millisekunden aufweisen.
 7. Verfahren nach Anspruch 6, wobei der erste Quadrantenwert 00, der zweite Quadrantenwert 01, der dritte Quadrantenwert 10 und der vierte Quadrantenwert 11 ist.
 8. Verfahren nach Anspruch 1, wobei der erste Wert des ersten Korrelationswerts 1 beträgt und wobei der zweite Wert des ersten Korrelationswerts 0 beträgt.
 9. Verfahren nach Anspruch 1, wobei die Phasenverschiebung, die den höchsten Gesamtkorrelationswert ergibt, die Phasenabweichung zwischen der ersten Wellenform und der zweiten Wellenform im gegebenen Fenster ist, wobei die Phasenverschiebung die optimale Verschiebung für die Phasenausrichtung der Wellenformen darstellt.

