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(54) Benævnelse: **DETEKTERING AF VANDINDTRÆNGNING I ET MELLEMLIGGENDE LAG UNDER ANVENDELSE AF EN AKUSTISK RESONANSTEKNOLOGI**

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WO-A1-86/01621
US-A- 4 313 791
US-A- 5 117 676
US-A- 5 663 503
US-A1- 2006 062 343
Lee Robins: "ON-LINE, NON-INTRUSIVE DIAGNOSTIC TECHNIQUES FOR PIPELINE INSPECTION AND FLOW ASSURANCE", , 31 December 2003 (2003-12-31), pages 1-11, XP055331451, Retrieved from the Internet: URL:http://www.ppsa-online.com/papers/2003 -3-Robins.pdf [retrieved on 2016-12-23]
WEISE V.L.,ET AL.: 'Investigation of moisture ingress into adhesive joints using ultrasonic and dielectric NDE techniques' REVIEW OF QUANTITATIVE NONDESTRUCTIVE EVALUATION vol. 21, 2002, pages 1165 - 1171, XP003025525

Fortsættes ...

DESCRIPTION

1 Introduction

[0001] The purpose of the present invention is to detect water ingress in the intermediate layer of a measurement object, having a cylindrical sandwich structure, such as that shown in Figure 5. Such piping structures are in use at the *Kårstø gas refinery* in Norway, and quested to be characterized by the present technique. Another relevant measurement object to characterize is sketched in Figure 6.

[0002] Generally, these measurement objects comprise an outermost solid material layer **510** Figure 5, which is significantly thinner than the internal layer; an intermediate layer **511,** having different acoustical impedance than the adjacent layers; and an internal solid material layer **512.** It is required that the thickness of the outermost layer is such that the SNR of the received half-wave resonance tail (Figure 4) can be made sufficient from which to extract thickness characteristics.

[0003] The method may alternatively be applied to characterize only parts of the described sandwich structure, such as the outermost layer **510** and possibly the intermediate layer **511.** The method might also be applied for cases in which either the outermost layer **510** or internal layers **512** are covered with coatings, or are corroded. In the latter case, several measurements will be utilized to smear out the presumed random nature of the corrosion topology, cf. Sec. 4.4, block **1040.**

[0004] WO 86/01621 describes a device for indication of water leakages in a heat insulated pipeline. The device includes two spaced electric conductors embedded in the insulation material. The conductors are covered with a water soluble layer.

[0005] Lee Robins: "ON-LINE, NON-INTRUSIVE DIAGNOSTIC TECHNIQUES FOR PIPELINE INSPECTION AND FLOW ASSURANCE", dated 31 December 2003, www.ppsa-online.com/papers/2003-3-Robins.pdf, describes radioactive methods for pipeline inspection. Moisture in the insulating layer of a pipeline may be detected by holding a source of high energy or "fast" neutrons and a detector sensitive to low energy or "slow" neutrons against the side of a pipeline. Fast neutrons from the source penetrate the wall of the pipeline and interact with the material behind the wall. If the material is hydrogenous, the neutrons are moderated by collision with the hydrogen nuclei. Slow neutrons diffusing back from the pipeline are detected.

2 Summary of the Invention

[0006] The present invention provides a device and method for detecting moisture ingress in an insulating layer surrounding a pipe as defined in the following independent claims 1 and 4. Preferred embodiments of the invention appear from the associated dependent claims.

3 The drawings.

[0007]

Figure 1. Functional diagram of measurement setup for detection of water ingress in intermediate layer. The labels refer to the following: 110 function generator; 120 power amplifier; 130 LF transmitting matching filter; 131 HF transmitting matching filter; 140 LF ultrasonic transceiver; 141 HF ultrasonic transceiver; 150 measurement object; 160 preamplifier; 170 data acquisition system; 180 control PC.

Figure 2 generic wide band (sin(x)/x) pulse emitted from the function generator 110. The width and frequency content of the pulse is adapted to embrace the resonance frequencies of either the outermost 510 or internal layer 512 of the measurement object 150.

Figure 3. The primary echo due to the outermost layer of the measurement object 150, associated with a dry intermediate layer 511. The half-wave thickness resonance tail due to the outermost layer 510, from which the outermost layer 510 thickness is determined, is shown in the time window. ADC is an abbreviation for analogue to digital converter.

Figure 4. The primary echo due to the outermost layer of the measurement object 150, for the wet intermediate layer case 511. The half-wave thickness resonance tail due to the outermost layer 510, from which the outermost layer thickness 510 is determined, is shown.

Figure 5. Piping structure subject to measurement. The labels refer as follows: 510 outermost layer; 511 intermediate layer; 512 internal layer.

Figure 6. Sandwich structure subject to measurement. The labels refer as follows: 610 outermost layer; 611 intermediate layer; 612 internal layer.

Figure 7. Flow chart showing the overall structure in the data processing.

Figure 8. Division spectra (see text) for wet-dry, dry-dry, and wet-wet combinations of spectra from 6 independent measurements (cf. Figure 4 and Figure 5). The resonance frequency for the outermost layer is about 2 MHz in this case. Comparing different measurements recorded for dry (middle plot) and wet (right plot) conditions gives more or less flat spectra, whereas at the resonance frequency there is a significant difference between wet and dry conditions (left plot).

Figure 9 Flow chart showing the sub-procedure for correctly identifying the harmonic frequencies and assigning the correct order to each.

4 Methodology

4.1 Reference measurement at dry region

[0008] The following description refers mainly to Figure 1. The control PC **180** comprises suitable software to control the function generator **110** and the data acquisition system (DAQ) **170,** by setting relevant parameters. The transceiver **140** and **141** is initially clamped at an elevated reference position of the measurement object **150,** at which the intermediate layer is presumed not to be wetted by a liquid.

[0009] Now the operator enables the function generator **110** (using a button), via the control PC **180,** to transmit an electrical wide-band pulse, such as the one in **Feil! Fant ikke referansekilden.,** to the power amplifier **120.** The wide-band pulse should at least cover a frequency band, referring to -3 dB, of

$$f \in [f_1, f_2], \quad f_i = \frac{c}{2d_i}, \quad i = 1,2, \qquad (1)$$

where *c* is the sound velocity of the outermost layer **110,** and d_1 and d_2 are respectively the maximum and minimum allowed thicknesses of the outermost layer **510** to be characterized. Hence, f_1 and f_2 represent the fundamental half-wave resonances associated with d_1 and d_2. Preferably, the upper frequency limit should embrace multiple harmonics.

[0010] The wide-band pulse is input at the power amplifier (PA) **120,** while the DAQ **170** is trigged to start digitizing and storing the electrical signal at its input. The PA **120** preferably amplifies the input wide-band pulse (Figure 2) linearly to a level slightly less than the maximum input level of the transmitting high-frequency (HF) part of the transceiver **140.**

[0011] The HF part of the transmitting matching filter **131** minimizes the impedance mismatch between the PA **120** and the transmitting HF part of the transceiver **141,** so as to maximize the electrical power input at the transmitting HF part of the transceiver **141.**

[0012] The HF transmitting part of the transceiver **141** transforms the input electrical pulse to mechanical vibrations. The mechanical vibrations generate a sound wave that propagates through the coupling medium, which may either be a waveguide or a gas, to the measurement object **150.** In case of a waveguide, it should preferably have a circular geometry, consist of some solid material, and possess acoustic impedance between that of the active transceiver element **141** and the outermost layer **510** (Figure 5).

[0013] The sound waves are partially reflected at the outermost layer of the measurement object **150,**

causing a *primary echo.* The primary echo travels back through the waveguide, and into the HF receiving part of the transceiver **141.** The primary echo is also received at the low-frequency (LF) part of the transceiver **140,** but considerably reduced, and considered negligible upon reception.

[0014] The HF receiving part of the transceiver **141** is excited by the primary echo to vibrate mechanically, and converts these mechanical vibrations to an electrical HF signal, which is input at the preamplifier **160.**

[0015] The preamplifier **160** amplifies the input electrical HF signal to a level similar to the input range of the DAQ **170.** Possibly, the preamplifier **170** may have embedded a switching circuit that disables the preamplifier output, if - for some reason - the DAQ saturates.

[0016] The DAQ **170** digitizes and stores the received HF signal as a reference measurement data result, comprising the primary echo (Figure 4). The measurement data result will henceforth be referred to as *time vector.*

4.2 Measurement at possible wet region

[0017] Next, the transceiver **140** and **141** is moved to a region of the measurement object **150** that is suspected to contain a wet intermediate layer **511,** preferably at a position directly below the presumed dry position. The measurement procedure described in Sec. 4.1 is then repeated, and the received signal is taken to be a measurement data set corresponding to a possible wet region.

[0018] An example of a resonance tail due to a wetted intermediate layer **511** is shown in Figure 4. In this case, a measurement setup such as that described in Sec. 4.1 facilitated the acquired signal. The measurement object **150,** immersed in fresh water at room temperature serving as coupling medium, consisted of a 1.5 mm steel plate **610,** adjacent to a practically half-infinite layer of water.

4.3 Measurement of thickness of internal layer

[0019] To be able to characterize the internal layer, it is required that the water column reaches the internal layer. Moreover, it is required that the thickness of the intermediate layer be greater than $\tau c_W/2$, where τ and c_W are respectively the time duration of the secondary echo inclusive tail, and sound velocity of the fresh water contained in the intermediate layer.

[0020] Upon reception of the above HF signal, the function generator **110** is trigged to transmit another electrical wide-band pulse, similar to the one in Figure 2, to the power amplifier **120.** Now the wide-band pulse should cover at least a frequency band, referring to -3 dB, of

$$f \in [f_1, f_2], \quad f_i = \frac{c}{2d_i}, \quad i = 1, 2, \qquad (2)$$

where c is the sound velocity of the internal layer **512,** and d_1 and d_2 are respectively the maximum and minimum allowed thicknesses of the internal layer **512** to be characterized. Hence, f_1 and f_2 represent the fundamental half-wave resonances associated with d_1 and d_2 for the internal layer **512.** Preferably, the upper frequency limit should embrace multiple harmonics. The present wide-band pulse will be referred to as wide-band LF pulse.

[0021] The wide-band LF pulse is input at the PA **120,** which preferably amplifies the wide-band LF pulse linearly to a level slightly less than the maximum input level of the transmitting LF part of the transceiver **140.**

[0022] The LF part of the transmitting matching filter **130** minimizes the impedance mismatch between the PA **120** and the transmitting LF part of the transceiver **140,** so as to maximize the electrical power input at the transmitting LF part of the transceiver **140.**

[0023] The LF transmitting part of the transceiver **140** converts the input electrical pulse to mechanical vibrations. These mechanical vibrations cause sound waves to propagate through the coupling medium to the outermost layer of the measurement object **150.**

[0024] The sound waves are partially transmitted through the outermost layer of the measurement object **150,** proceeding through the intermediate layer (Figure 5), to be reflected at the internal layer surface **512** (Figure 5). This reflection will be referred to as the *secondary echo.*

[0025] The secondary echo propagates back through the intermediate layer **511** (Figure 5), to be partly transmitted through the outermost layer **510** (Figure 5).
The secondary echo proceeds through the waveguide, into the LF receiving part of the transceiver **140.**

[0026] The receiving LF part of the transceiver **140** is excited by the secondary echo to vibrate mechanically, and these mechanical vibrations are converted to an electrical LF signal. The electrical LF signal is then input at the preamplifier **160.**

[0027] The preamplifier **160** amplifies the input electrical LF signal to a level similar to the input range of the DAQ **170.**

[0028] The DAQ **170** digitizes and stores the received LF signal, comprising the secondary echo.

4.4 Data analysis

710 Time vector

[0029] The set of real numbers corresponding to voltages from the DAQ unit **170.**

720 Input parameters

[0030]

- Speed of sound of outer layer, c
- Speed of sound of wet intermediate layer **511,** c_W
- Length of time window for spectral estimation, N
- Expected width of primary echo without resonance tail, W
- Spectral estimation methods
- Choice of window functions (e.g. Hanning, Bartley)
- Sampling frequency, F_S
- Frequency interval used in transceiver
- Expected outer layer **510** thickness
- The thickness of the intermediate layer **511,** ℓ
- Maximum allowed lag of secondary peak from its theoretical arrival, k
- Number of datasets in reference memory, M

810 Time-frequency analysis

[0031] Inputs: time signal, spectral estimation technique, N, F_S

[0032] The power content in the time-frequency domain is estimated, using any standard technique, such as the sliding Fourier transform, or the Wigner distribution. The time of the maximum energy is identified, from this and N the start time of the tail is found.

[0033] Time-frequency analysis is processing intensive and can be switched off.

[0034] Outputs: matrix of power, vector of times (in units of sampling interval), vector of frequencies (in Hz), start of tail time

910 Identify primary echo

[0035] Inputs: time vector, expected width of primary echo

[0036] Finds the time corresponding to the largest pulse energy, and uses expected width of primary echo to find the start and stop of the echo

[0037] Outputs: start and stop times of echo

911 Identify secondary echo

[0038] Inputs: c_W, ℓ, *k,* time vector, start and stop times of primary echo

[0039] The rough peak location of the secondary echo is found from

$$\tau_1 = \tau_0 + \frac{2\ell}{c_w},$$

where τ_0 is the time of arrival of the primary echo (which is found as the midpoint between the start time and end time of the echo), ℓ is the thickness of the intermediate layer **511.** The nearest local maximum in the signal energy is deemed to be the time of arrival of the secondary echo. If that local maximum falls outside the range given by *k,* the start and end of secondary echo are left empty.

[0040] Outputs: start and stop times of secondary echo

920 Abort?

[0041] Inputs: start and stop times of secondary echo

[0042] If the inputs are empty, abort the calculation of internal layer **512** thickness because no echo could be identified.

[0043] Outputs: whether secondary echo was found

930 Spectral estimation

[0044] Inputs: time vector, spectral estimation method, start and stop times for analysis, window functions, *N,* F_S

[0045] The frequency power content of the time signal is estimated using any standard technique, from periodogram based methods to parametric methods, for example using the Yule-Walker model. The estimation is performed in two windows, one comprising the tail only (starting at end of echo lasting to end of echo + *N*), and one comprising the echo and its tail, starting at the time start of echo - *N* lasting to end of echo + *N.*

[0046] Outputs: power vector tail, vector with frequencies (in Hz) corresponding to the power values, power vector echo, vector with frequencies (in Hz) corresponding to the power values

940 Identification of resonance frequencies

[0047] Inputs: frequency vector from **Time-frequency analysis** and/or **Spectral estimation,** power matrix and/or power vector tail, frequency interval used in transceiver, start of tail time in time-frequency vector

[0048] Either one or both of the following:

1. 1. The resonance frequency is identified as the maximum energy in the power vector inside the frequency interval of the transceiver **141**
2. 2. The resonance frequency is identified as the most prominent exponentially decreasing (in time) frequency in the time-frequency matrix, inside the time interval of the tail and inside the frequency interval determined by frequency interval used in transceiver **141.**

[0049] Outputs: index into time and frequency vectors corresponding to the resonance frequency

970 Identification of resonance frequencies - search for harmonic sets

[0050] Inputs: frequency vector tail, frequency vector echo, power vector tail, power vector echo

[0051] An elaborate procedure is required to achieve a reliable determination of harmonic orders belonging to frequencies. The procedure is detailed in 971-979 below.

[0052] Outputs: harmonic orders, resonance frequencies

950 Thickness computation

[0053] Inputs: *c*, resonance frequencies, harmonic orders

[0054] The layer thickness is computed from

$$d = \frac{c}{2f_{res}}, \qquad (2)$$

where f_{res} is the resonance frequency. If the wide band pulse produced by the transceiver **140** and **141** covers several harmonic orders of the resonance frequency, a more reliable method for thickness computation calculates

$$d = \left\langle \frac{cn}{2f_{res}} \right\rangle, \qquad (3)$$

where now *n* is the integer indicating the harmonic order and <·> indicates averaging.

Display results.

[0055] Outputs: thickness estimates

960 Display results

1010 Decay times

[0056] Inputs: time-frequency power matrix, vector of frequencies, start of tail time

[0057] The characteristic decay time of the resonance in the tail is found.

[0058] Outputs: the decay time of the resonance frequency

1020 Energy of resonance frequencies

[0059] Inputs: power vector tail, power vector echo, index of resonance frequency

[0060] Reads the values in the power vectors

[0061] Outputs: power at resonance frequency in tail, power at resonance frequency in echo

1030 Comparison

[0062] Inputs: power of resonance frequency in tail, power vector echo, decay time, reference power of resonance frequency in tail, reference power vector echo, reference decay time

[0063] Reference variables are vectors comprising several previous realisations, the exact number determined by the input variable *M* (see above under **Input parameters**).

[0064] Initialisation of comparison: one or more data sets are recorded at location(s) known to be dry. The readings are analysed using the above steps, and the power spectrum in echo, decay time of resonance frequency in the tails, and lastly the maximum power of the resonance frequency in the tail, are stored. All the features are classified as "dry".

[0065] The new data comprising the power of resonance frequencies in tail, power vector echo, and the decay time, are compared with their respective reference values in the following manner:

1. 1. the decay time is subtracted from the reference values, henceforth referred to as difference decay times
2. 2. the power of resonance frequency in the tail is subtracted from the reference values, henceforth referred to as difference powers
3. 3. the power vector echo is divided by the references, from this point referred to as division spectra

An example of the output resulting from 3) is illustrated in Ifure 8. Spectra have been calculated for 6 different time sequences, $P_i(f)$, i = 1,...,6, with water present in the intermediate layer for i=1,2,3. The plots were produced by dividing pairs of spectra, $P_i(f)/ P_j(f)$. To the left is shown results when both spectra correspond to wet conditions (i,j=1,2,3), the middle plot shows dry conditions (i,j=4,5,6), whereas the leftmost plot shows one each (i=1,2,3 and j=4,5,6). When both spectra correspond to identical conditions, the ratio is flat for all frequencies, whereas for different conditions the resonance frequency of the outermost layer is distinctly different and shows up as a clear feature (a peak in this case) in the division spectrum.

[0066] Outputs: division spectra, difference powers, difference decay times

1040 Wet/dry determination

[0067] Inputs: division spectra, difference powers, difference decay times, power vector tail, resonance frequency, previous result (wet/dry), *M*

[0068] For each of the comparisons one must determine whether they are consistent with wet or dry conditions. This is done in the following manner:

1. 1. decay time: if *M* wet references and *M* dry references are available, compute the mean decay time in each case. Classify as "dry" if the decay time is closer to the "dry" mean, and correspondingly for "wet". If not all references are available, do not contribute to the decision, but keep the number for reference.
2. 2. resonance power tail: if *M* wet references and *M* dry references are available, compute the mean resonance power tail in each case. Classify as "dry" if the resonance power tail is closer to the "dry" mean, and correspondingly for "wet". If not all references are available, do not contribute to the decision, but keep the number for reference.
3. 3. the division spectra are each analysed for a distinct feature at the resonance frequency. Such a feature indicates change (from wet to dry or from dry to wet). The change/no change results are stored in a vector.

A simple majority voting is then used to classify the measurement as indicating either "dry" or "wet" conditions.

[0069] According to the decision, the power vector tail, the power vector echo, and decay time are stored as a reference in either the "wet" or "dry" class. If the number of stored references is equal to *M,* the currently obtained results replace the oldest reference.

[0070] Output: display result, new reference values.

1050 Reference for the wet case

1060 Reference for the dry case

1070 Display results

Undescribed actions

[0071] The original time vector is stored.

[0072] All display functions in the flow chart imply storage.

971 Find local maxima/minima

[0073] Inputs: power vector echo, power vector tail, bispectrum vector

[0074] Finds local maxima in the bispectrum vector and the power vector tail. Finds local minima in the power vector echo.

[0075] The union of the three sets is the list of potential harmonic frequency candidates.

[0076] Outputs: harmonic frequency candidates

972 Weighting of maxima/minima

[0077] Inputs: harmonic frequency candidates, power vector echo, power vector tail, bispectrum vector, filter size

1. 1. Initialise weights vectors with values zero except at harmonic frequency candidates, where the value from the power vectors is used for bispectrum and tail. The weight vectors are normalised to the largest value in each case, e.g. all weights from the bispectrum candidate frequencies are normalised to the maximum value in the bispectrum vector.
2. 2. subtract the power vector echo with its filtered version. The difference at the local minima defines the weight in this case. Normalise.
3. 3. One now has available three sets of weights, W_{bisp}, W_{tail}, W_{echo}, each normalised so the largest weight is 1.
4. 4. For each set, scale the weights by
   $$W_j(i) = W_j(i)\prod_{k \neq j} \exp(-d_k)$$
   where d_k is the shortest distance to a non-zero weight in set k. W_j (i) is the ith element of the jth set.
5. 5. sum the weights from each set to obtain a single weight vector

[0078] The ensuing weight vector gives weight to large peaks/deep minima in the respective power vectors, but penalises each weight if it is far from frequencies in the other sets. Weights are real numbers between 0 and 1.

[0079] Outputs: weights assigned to each harmonic frequency candidate

973 Sort according to weights

[0080] Inputs: weights, harmonic frequency candidates

[0081] Sorts the weights vector, and uses the sort indices to rearrange the harmonic frequency candidates so that they are listed in decreasing weighted order.

[0082] Outputs: sorted harmonic frequency candidates

974 Build frequency sets

[0083] Inputs: sorted harmonic frequency candidates, weights, frequency weights threshold

1. 1. Reject all candidate frequencies below the threshold
2. 2. Rearrange frequency candidates into sets. If there are N candidates, then build N lists $\{f_1, ..., f_N\}$, $\{f_1, ... , f_{N-1}\}$, and so on, where the smallest weighted frequency in the previous list is progressively removed. Each list is henceforth known as a frequency set.

Each frequency set is denoted F_n.

[0084] Outputs: frequency sets $\{F_1, F_2,.., F_N\}$

975 Loop through n=1,...,N

976 Find harmonic sets

[0085] Input: Frequency sets $\{F_1, F_2,.., F_N\}$, integer tolerance, expected maximum thickness, frequency interval used in transceiver

[0086] The harmonic sets for one frequency list F_i is computed as follows: initially a $n \times n$ matrix with filled with all possible ratios of frequencies is found,

$$M'_{ij} = \frac{f_i}{f_j}$$

The matrix **M'** is used to build a larger matrix **M** by concatenating $k\mathbf{M}', k = 1,2,\cdots,k_{\max}$ as follows:

$$\mathbf{M} = \begin{bmatrix} 1 \cdot \mathbf{M'} \\ \vdots \\ k_{\max} \cdot \mathbf{M'} \end{bmatrix}$$

[0087] The integer $k_{\max}$ is computed from the maximum allowed thickness, a user input.

[0088] The next step is to round all elements in **M** to their nearest integer, and compare the difference between the integer values and the frequency ratios in **M .** An element is deemed an integer if this difference is less than a user specified threshold, typically 0.1, and a matrix **N** where all non-integer elements in **M** equal zero if found. The rows in **N** identify the harmonic sets: for a given N_{ij} element the value corresponds to the harmonic order of frequency f_j in the frequency list.

[0089] Ouput: Set of integer matrices $\{N_1, N_2,.., N_N\}$.

977 Removing elements in N_n:

[0090] Input: Set of integer matrices $\{N_1, N_2,.., N_n\}$, expected maximum thickness, frequency interval used in transceiver

[0091] The harmonic order matrices N_n are significantly reduced by removing rows containing a value above the max order k_{max}. All duplicate rows are removed, and rows giving a thickness above the user input maximum value are removed.

[0092] Outputs: Set of reduced integer matrices $\{N_1, N_2,.., N_n\}$.

978 Count number of harmonics in N_i:

[0093] Input: Set of reduced integer matrices $\{N_1, N_2,.., N_n\}$.

[0094] For each N_n, the harmonic set with the largest number of unique frequencies are recorded. The numbers are stored in a vector Φ.

[0095] Output: VectorΦ of maximum number of unique sets.

979 Finding optimum subset of frequencies:

[0096] Input: Vector Φ of maximum number of unique sets, number of frequencies in each frequency set, set of reduced integer matrices $\{N_1, N_2,.., N_n\}$.

[0097] The aim is to find the optimum subset of the original frequency list. Each subset is associated with a number of unique harmonics stored in Φ. In addition, each subset has a number of frequencies.

[0098] The optimal subset is found by finding the *highest* ratio of Φ divided by the number of frequencies in the list, neglecting the trivial case for only a single frequency. In this process we have accomplished both a rejection of frequencies, *and* obtained harmonic sets.

[0099] Output: Indices to optimal subset of frequencies, set of harmonics.

4.5 Liquid level determination

[0100] Upon positive detection of liquid in the intermediate layer **511,** the transceiver **140** and **141** is moved upwards in steps of, say 10 mm, towards elevated regions of the measurement object **150.** Meanwhile, the procedures described in Secs. 4.1 to 4.4 are repeatedly performed, to determine at which level the liquid surface occurs.

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- WO8601621A [0004]

Non-patent literature cited in the description

- **LEE ROBINS**ON-LINE, NON-INTRUSIVE DIAGNOSTIC TECHNIQUES FOR PIPELINE INSPECTION AND FLOW ASSURANCE, 2003, [0005]

Patentkrav

1. Apparat til at bestemme fugtindtrængning i et isolerende lag (511), der omgiver et rør (512), hvor nævnte isoleringslag (511) er omgivet af en rørformet kappe (510), hvor nævnte apparat omfatter

en akustisk transducer (140, 141), der er i kommunikation med en exciter (110), der er indrettet til at tilvejebringe et bredbånds akustisk signal, der omfatter frekvenser, som ved udbredelse i materialet af kappen, har en bølgelængde, der svarer til det dobbelte af tykkelsen af jakken eller en ulig flerlagsdel af det dobbelte af tykkelsen af kappen,

signalbehandlingsmodtager (170, 180), der er i kommunikation med transduceren og indrettet til at modtage og behandle et efterklangssignal, der er udsendt af kappen som respons på at transmittere ind i kappen det akustiske bredbånssignal fra transduceren,

kendetegnet ved, at signalbehandlingsmodtageren (170, 180) er indrettet til at udføre en frekvensanalyse af det modtagede efterklangssignal, der identificerer et primært ekko og et sekundært ekko, der omfatter en ende, hvor et frekvenseffektspektrum af det reflekterede signal estimeres, resonansfrekvensen eller harmoniske sæt af resonansfrekvenser i det reflekterede signal identificeres, henfaldstiden for resonansen eller resonanserne identificeres, effekten af det reflekterede signal ved resonansfrekvensen eller frekvenserne identificeres og enhver fugtindtrængning i det isolerende lag (511) bestemmes ved at sammenligne henfaldstiden for resonansfrekvensen eller frekvenserne i enden, maksimal effekt ved resonansfrekvensen eller frekvenserne i enden og frekvenseffektspektrummet af det reflekterede signal med referenceværdier for tørre og våde forhold i det isolerende lag (511).

2. Apparat ifølge krav 1, hvor bredbåndstransduceren er tilpasset til drift ved en midterfrekvens på omkring 4,3 MHz.

3. Apparat ifølge krav 1 eller 2, hvor signalbehandlingsudstyret kan betjenes til at normalisere frekvenseffektspektrummet og, på basis af det normaliserede frekvenseffektspektrum, at beregne en faktisk fugtighedsindholdsværdi.

4. Fremgangsmåde til at bestemme fugtindtrængning i et isolerende lag (511), der omgiver et rør (512), idet isoleringslaget (511) er omgivet af en rørformet kappe (510), hvor nævnte fremgangsmåde omfatter at tilvejebringe et apparat, der omfatter en akustisk transducer (140, 141), der er i kommunikation med en exciter (110), der er indrettet til at tilvejebringe et akustisk bredbåndssignal, som omfatter frekvenser, som ved udbredelse i kappen har en bølgelængde, der svarer til det dobbelte af tykkelsen af kappen eller et ulige multipel af det dobbelte af tykkelsen af kappen, en signalbehandlingsmodtager (170, 180), der er i kommunikation med transduceren (140, 141) og indrettet til at modtage og behandle et efterklangssignal, der er udsendt fra kappen som respons på at sende ind i kappen det akustiske bredbåndssignal,
kendetegnet ved, at en frekvensanalyse af det modtagne eferklangssignal fremstilles, der omfatter trinnene:

at identificere et primært ekko og et sekundært ekko, omfattende en ende,
at estimere et frekvenseffektspektrum af det reflekterede signal (930),
at identificere resonansfrekvensen, eller harmoniske sæt af resonansfrekvenser, i det reflekterede signal (940, 970),
at identificere henfaldstiden for resonansen/resonanserne (1010),
at identificere effekten af det reflekterede signal ved resonansfrekvensen eller frekvenserne (1020), og
at bestemme om der er nogen fugtindtrængning i det isolerende lag ved at sammenligne henfaldstiden for resonansfrekvensen eller frekvenserne i enden, maksimal effekt ved resonansfrekvensen eller frekvenserne i enden og frekvenseffektspektrum for det reflekterende signal med referenceværdier for tørre og våde forhold i det isolerende lag (1030, 1040).

5. Fremgangsmåde ifølge krav 4, yderligere omfattende at tilpasse bredbåndstransduceren til drift med en midterfrekvens på omkring 4,3 MHz.

6. Fremgangsmåde ifølge krav 4 eller 5, yderligere omfattende trinnene med at normalisere frekvenseffekspektrummet og til at beregne en faktisk fugtighedsindholdsværdi baseret på det normaliserede frekvenseffekspektrum.

DRAWINGS

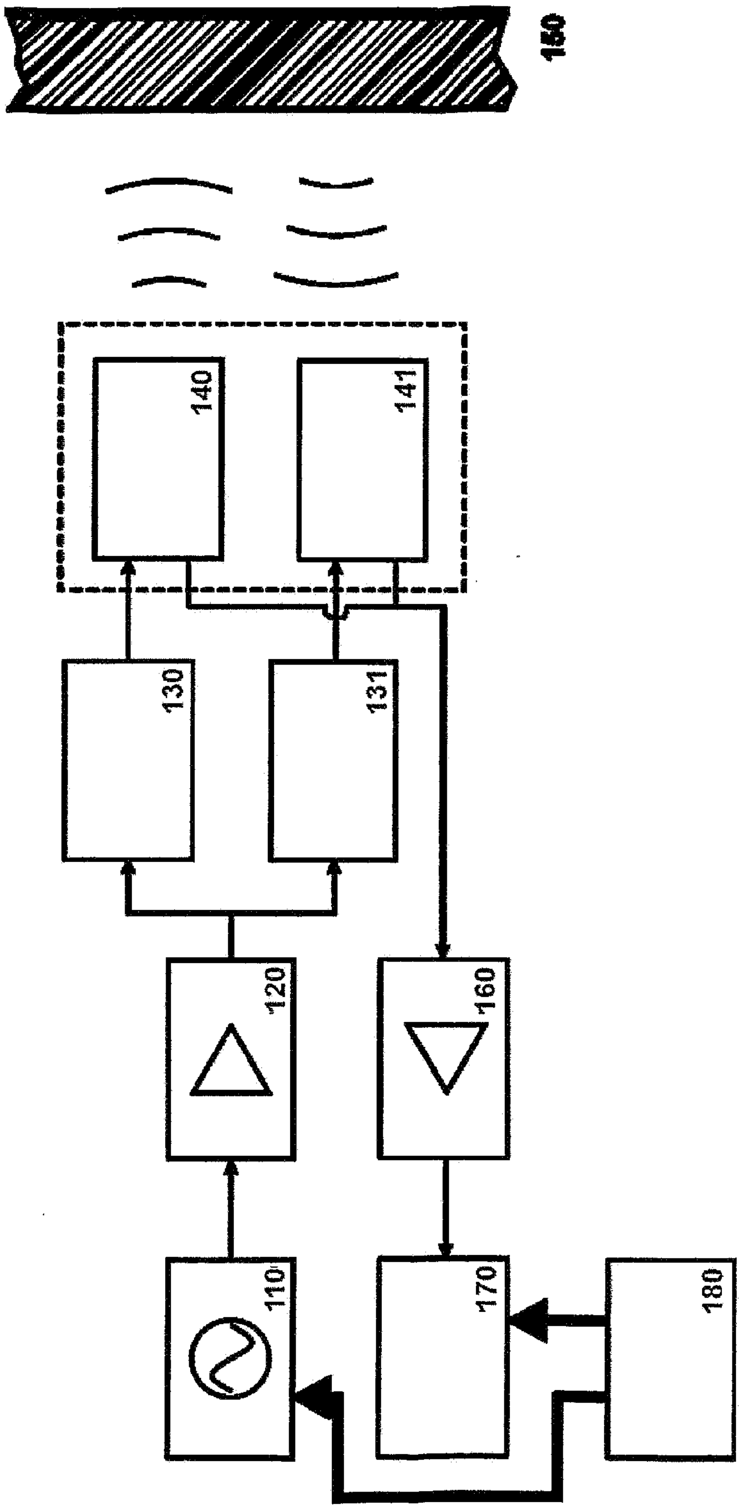

FIG.1

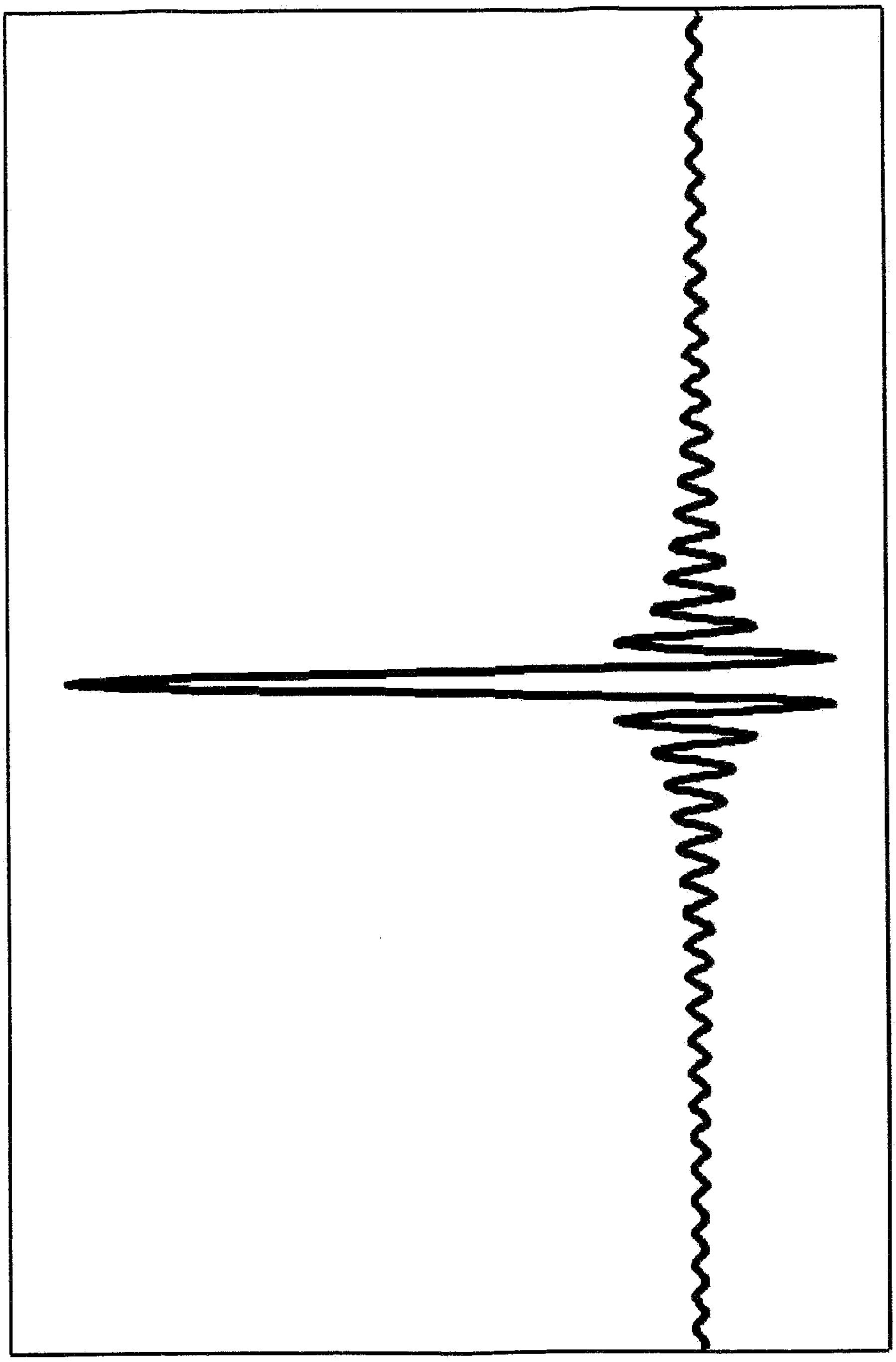

FIG.2

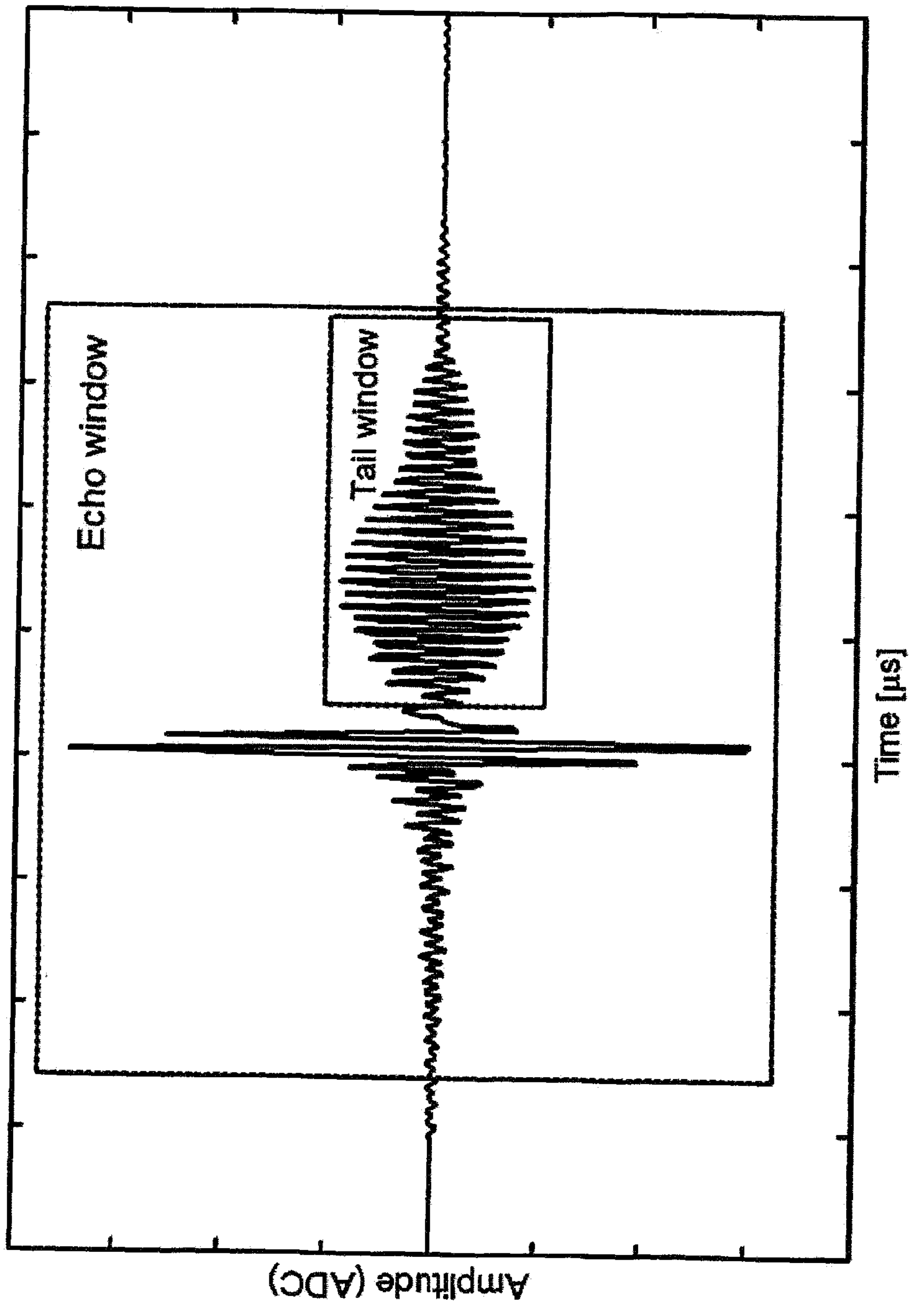

FIG.3

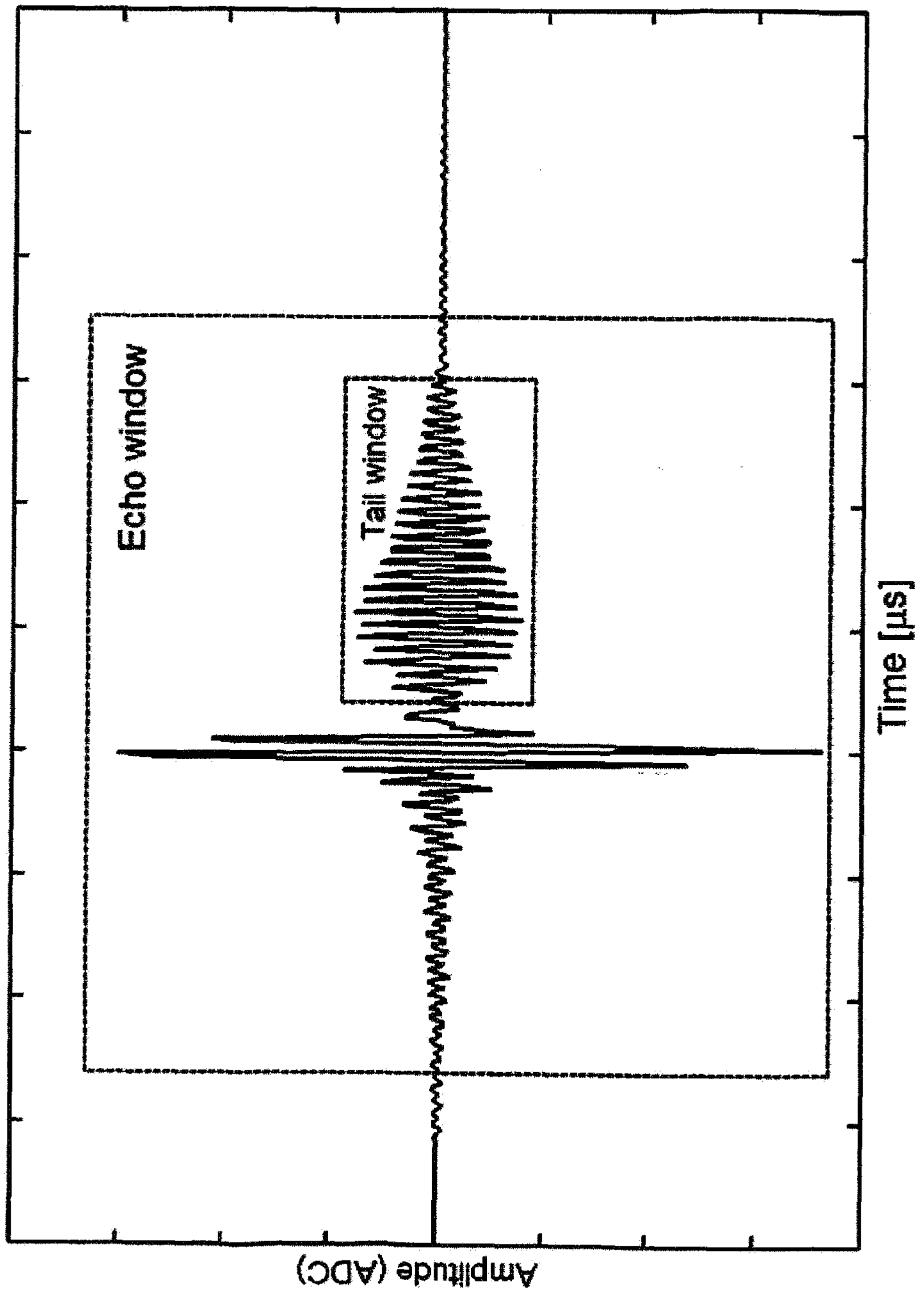

FIG.4

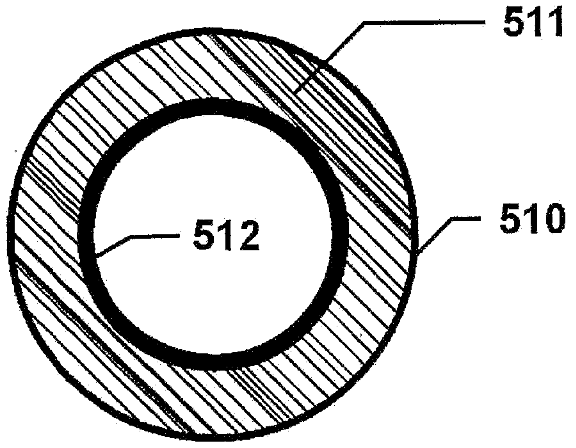

FIG.5

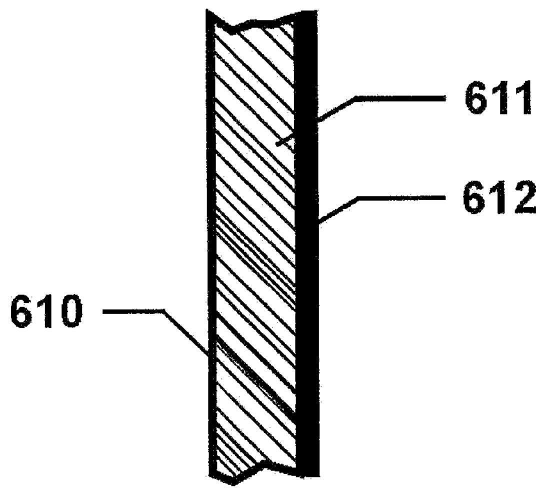

FIG.6

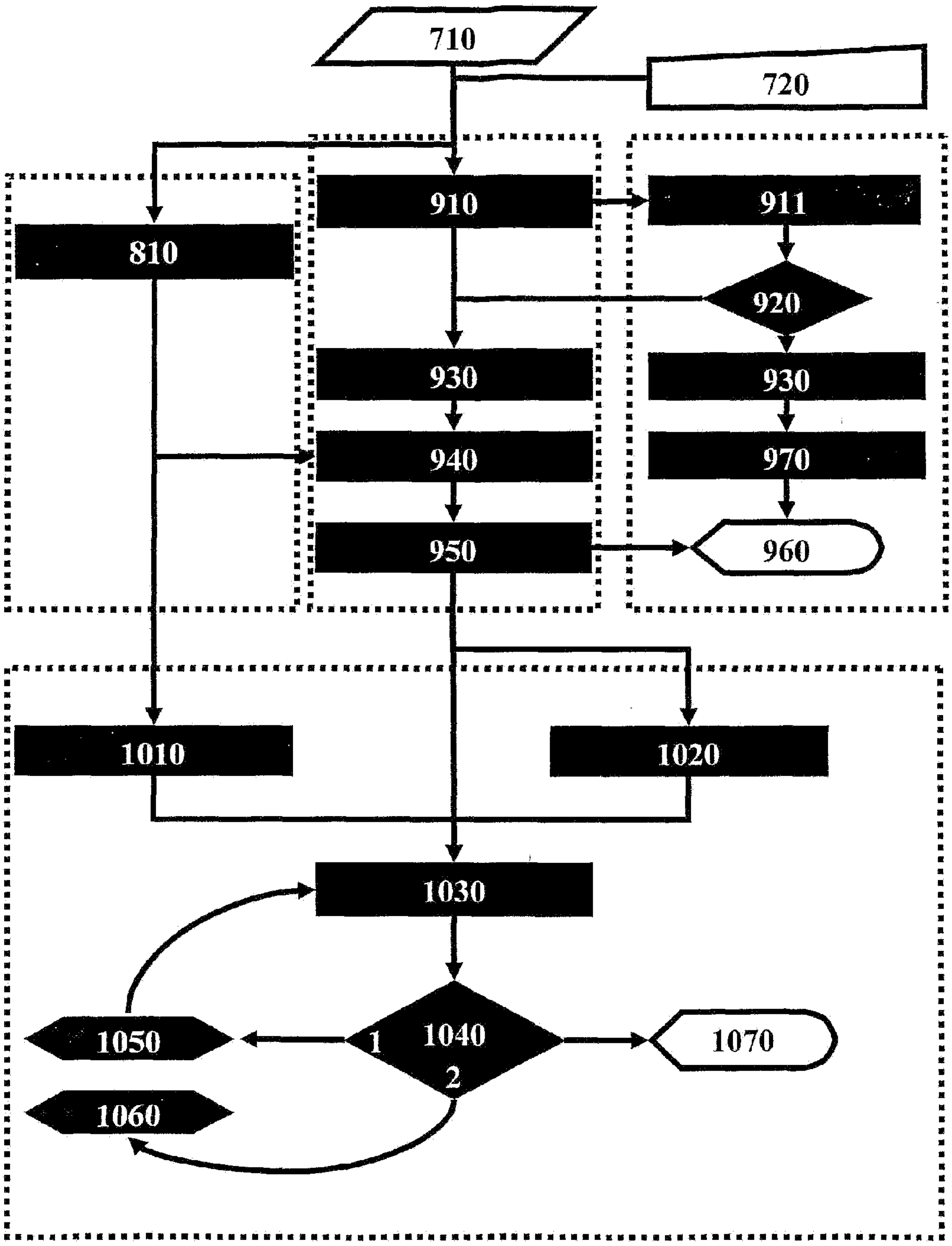
710
720
810
910
911
920
930
930
940
970
950
960
1010
1020
1030
1050
1
1040
2
1070
1060

FIG.7

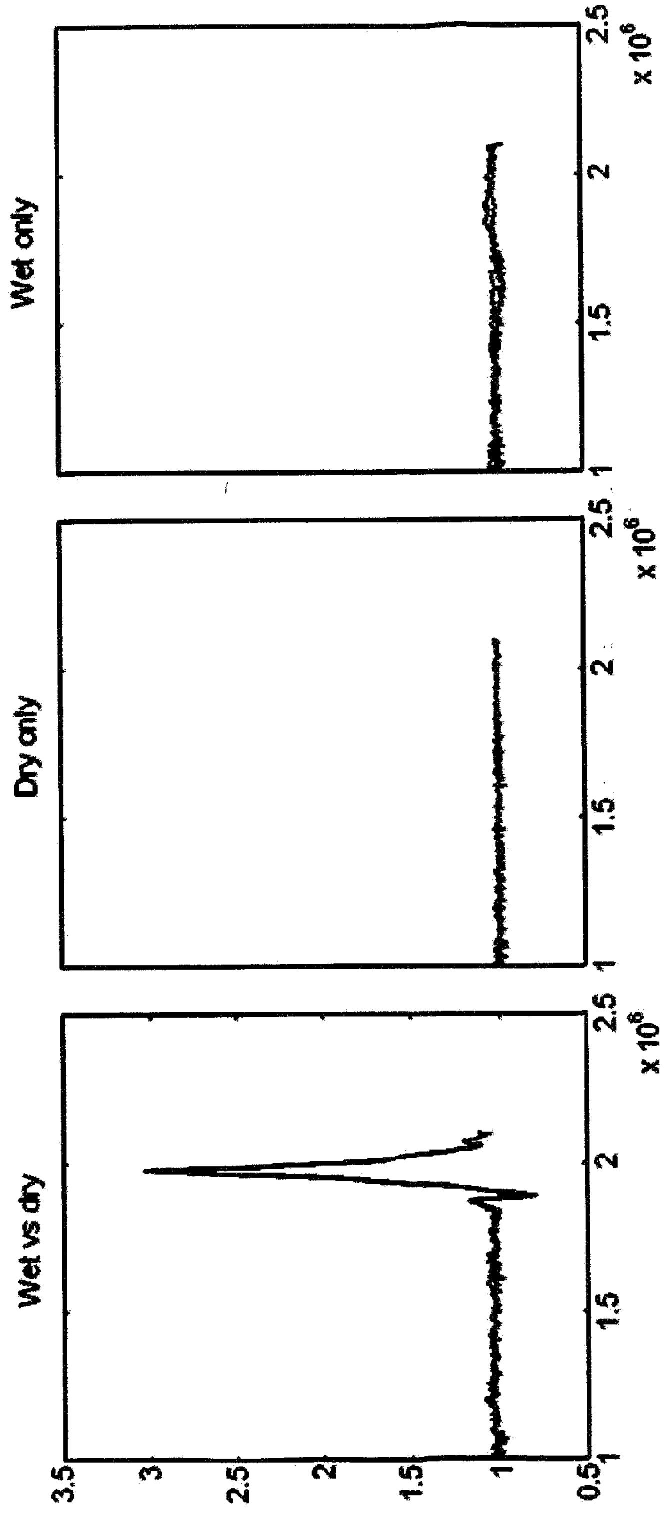

FIG.8

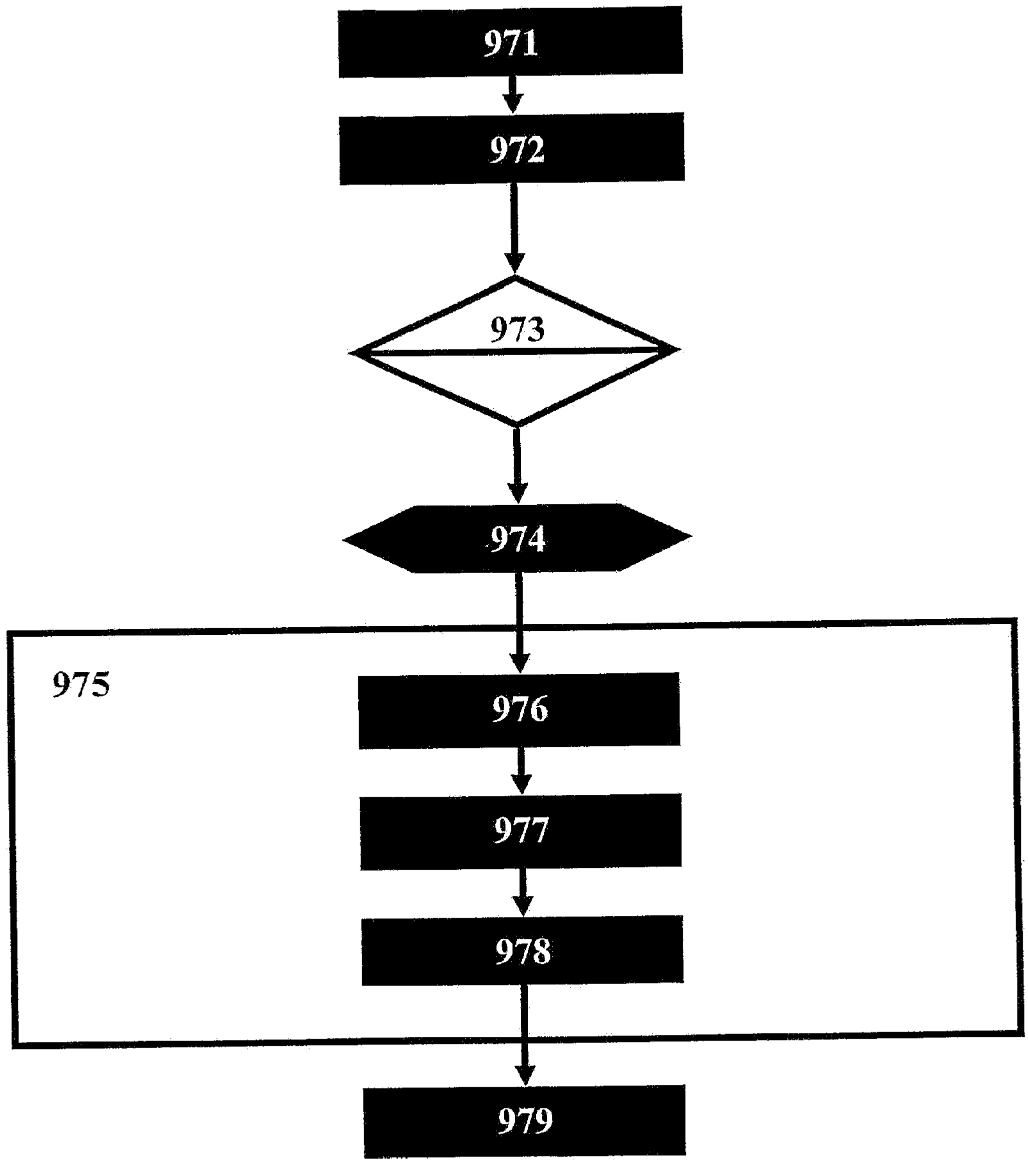

FIG.9