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(54) **Ultrasonic Phased Array Approach.**

(57) A method for inspecting an object (102), the method comprising the following steps:
a. coupling a first transmitter phased array ultrasonic transducer (104) to a first surface of the object;
b. emitting by means of the transducer an ultrasonic wave into the object under a first angle relative to a normal of the first surface at the position of the transducer so that the wave propagates in the object between the first surface of the object and a second surface of the object while in succession being reflected in the object at the second surface and the first surface respectively, so called multiple skip and detecting the wave propagating through the object;
c. repeating step b. at least one time for another angle than the first angle and/or another transducer position wherein the position of the transducer is varied in a direction x along the first surface from the transducer to a zone of the object to be inspected and/or in a direction along the surface perpendicular to the direction x;
d. combining the detected waves and producing based on the combined detected waves a image representing at least a first portion of the inner volume of the object on a screen wherein the first portion of the inner volume corresponds to a position which is offset relative to the normal.

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Titel: Ultrasonic Phased Array Approach

The present invention relates to a method for inspecting an object such as a metal pipeline or a metal storage tank by means of ultrasonic waves. Such a method is known. The known method comprises the following steps:

a. coupling an ultrasonic transducer to a first surface of the object;

b. emitting by means of the transducer ultrasonic waves into the object and detecting reflected and/or diffracted waves from the object;

c. combining the detected waves and producing based on the combined detected waves a image representing al least a first portion of the inner volume of the object on a screen.

Such types of inspections are carried out because an integrity of an object can be reduced due to degradation, for example corrosion when water is in contact with a metal object. The integrity assessment of installations is difficult for locations that are not directly accessible for inspection (visually or using non-destructive testing) due to an obstacle like a support or foundation. Some locations are difficult to inspect while (local) degradation is likely to occur, like the bottom plates of storage tanks or the location where pipes are in contact with supports, often referred to as CUPS (Corrosion Under Pipe Supports). Such situations exist worldwide in various industries like chemical, oil and gas, power.

Installations are exposed to environmental conditions like rain or moist which is in many cases a cause for corrosion. If the installation is allowed to dry then the impact will be small. However, some locations tend to ‘collect’ moist and will only dry slowly, if at all. Examples are water ingress under a storage tank bottom or between a pipe and a support. Other degradation mechanisms (not specified here) could also occur at inaccessible areas. Local circumstances influence the degradation process but are not considered here, like temperature, materials, design and maintenance. Degradation of an installation can lead to leakage or failure with impact on personal safety, environmental damages, loss of production, downtime and unplanned repairs. To prevent such situations the industries want to evaluate the integrity of installations before failure and take preventive actions. This requires a timely and reliable inspection, also of inaccessible parts.

Making the locations accessible for conventional inspection (like visual inspection or straight beam ultrasonic thickness measurement) is often not a practical/economical option because it requires significant preparations like emptying the tank for measurement of the storage tank bottom from the top side, excavating under the storage tank bottom, entrance into the pipe for measurement of the pipe wall from the inside, or lifting the pipe from the support.

For inaccessible locations the existing inspection solutions are inaccurate, impractical, time consuming, difficult to interpret or require specialized equipment.

Using a single conventional ultrasonic transducer, typically using a shear wave angled beam, will provide only limited results because the signals received by the transducer after reflection on the corrosion will depend strongly on the combination of the impinging beam direction and the shape/orientation of the corrosion. Only part of the reflected signals will be recorded by the transducer. Using multiple transducers, each having a different beam angle, requires more steps during the examination and also an appropriate combination of data during evaluation.

Some ultrasonic methods use a transmission method with two transducers, one on either side of the area under examination, like CHIME and Multi-Skip. This requires access on both sides of the pipe support and a dedicated manipulator to maintain a fixed distance and orientation while moving the transducers simultaneously in circumferential direction around the pipe. Obviously, this setup is not suitable for the bottom plates of storage tanks.

Radiographic examination is not suitable for storage tank bottom plates because it requires access on both sides and it has typically very limited performance on pipe on supports because of restrictions to properly align the source, area under examination and the film.

The object of the invention is to provide a solution to these problems.

The method according to the invention comprises the following steps:

a. coupling a first transmitter phased array ultrasonic transducer (104) to a first surface of the object;

b. emitting by means of the transducer an ultrasonic wave into the object under a first angle relative to a normal of the first surface at the position of the transducer so that the wave propagates in the object between the first surface of the object and a second surface of the object while in succession being reflected in the object at the second surface and the first surface respectively multiple times, so called multiple skip (one skip is defined as a wave coming from the first surface, reflecting at the second surface and arriving at the first surface again) and detecting the wave propagating through the object;

c. repeating step b. at least one time for another angle than the first angle and/or another transducer position wherein the position of the transducer is varied in a direction from the transducer to a zone of the object to be inspected;

d. combining the detected waves and producing based on the combined detected waves a image representing at least a first portion of the inner volume of the object on a screen wherein the first portion of the inner volume corresponds to a position which is offset relative to the normal.

Because by means of the phased array transducer step b can be repeated for multiple different angles on the one hand and wherein the waves propagates through the object by means of multiple internal reflection to locations of the object which can not be directly accessed by means of ultrasonic techniques using direct beams, on the other hand sufficient information can be obtained for creating an image of that location.

This solution is intended for the inspection of inaccessible locations, like bottom plates of storage tanks or pipes in contact with supports, for various industries like chemical, oil and gas, power. For bottom plates of storage tanks only the outer part of the bottom plates can be examined (e.g. 0.5 – 1.5 meters), not the entire tank bottom. For pipe supports various designs are known, from direct contact (generally susceptible to corrosion) to clamped or welded supports.

The examples in this document mention external corrosion of the installation due to water, but also other degradation mechanisms can be inspected like internal corrosion or erosion.

Thus it is possible to carry out the method with one single transducer and optionally a wedge if the same phased array transducer is used for transmitting and receiving. It is however also possible that a separate phased array transducer is used for the detection of the waves.

Thus as an aspect of the invention, a method for inspecting an object, such as a pipe or plate, especially inaccessible parts of a pipe or plate, such as sections of pipes obstructed by supports or clamps, annular and bottom plates of storage tanks, is provided. The method including coupling a transmitter phased array ultrasonic transducer to one of the surfaces of the object to emit shear waves in the object; coupling a receiver phased array ultrasonic transducer to one of the surfaces of the object to detect ultrasonic waves propagating through the object.

The transmitter phased array ultrasonic transducer and the receiver may be separately transducers, which are spaced apart for each other up to 0.5 metre or more, and they may be placed to the same or to opposite surfaces of the object. Alternatively, the transmitter phased array ultrasonic transducer may be the same transducer with the receiver in some circumstances where the ultrasonic waves are reflected back to the transmitter by any discontinuity in the object, such as crack, corrosion, or edge of the object.

The method may further comprise collecting ultrasonic data from the object and analysing the data to detect discontinuities therein. Conducting the phased array ultrasonic inspection may include using ultrasonic testing techniques consisting of electronic scanning, sectorial scanning, dynamic depth focusing, and a combination thereof.

As another aspect of the invention, a phased array ultrasonic testing system is provided for testing the inaccessible components in accordance with the method of the invention. The phased array ultrasonic testing system may include a phased array ultrasonic set, a computer, a scanner with an encoder and one/two phased array transducer(s) working in pitch-catch and/or pulse-echo mode. The phased array ultrasonic set and a computer are used for phased array ultrasonic data acquisition to define a plurality of focal laws of ultrasonic beams controlling the emission/receiving of the ultrasonic beams from the phased array ultrasonic transducers, and analysis. And the scanner with an encoder is to manipulate the transducer(s) into desired positions in order to perform the inspection. Alternatively the transducer is manipulated manually into desired positions while an encoder registers the position of the transducer in order to perform the inspection.

The invention will be further described in the preferred embodiments with reference to the accompanying drawings in which:

Fig. 1 shows a schematic sectional view of an apparatus for phased array ultrasonic inspection of a bottom plate in one tank;

Fig. 2a shows B-scan obtained using the apparatus of Fig. 1 wherein the horizontal axis denotes the position y as shown in Fig. 1 and the vertical axis denotes time t along beam axis (alternatively, the vertical axis denotes depth d);

Fig. 2b shows C-scan obtained using the apparatus of Fig. 1 wherein the horizontal axis denotes the position y and the vertical axis denotes the position x as shown in Fig. 1;

Fig. 2c shows Sectorial scan obtained using the apparatus of Fig. 1 wherein the horizontal axis denotes the position x as shown in Fig. 1 and the vertical axis denotes depth ;

Fig. 2d shows a cross-sectional view of an object wherein one transmitted beam is shown which is internally reflected 5 times (multiple skip);

Fig. 2e shows a linear scan obtained using the apparatus of Fig.1 wherein the horizontal axis denotes the position x as shown in Fig. 1 and the vertical axis denotes depth;

Fig. 3a shows a schematic sectional view of an apparatus for phased array ultrasonic inspection of a pipe on a support;

Fig. 3b shows Sectorial scan obtained using the apparatus of Fig. 3a wherein the horizontal axis denotes the position x as shown in Fig. 3a and the vertical axis denotes depth ;

Fig. 4 shows a steep sectorial scan inspection of a first fillet weld;

Fig. 5 shows a less steep sectorial scan inspection of a second fillet weld;

Fig. 6 shows a typical scan plan, 3 skips

Fig. 7 shows a shallow angle to inspect deep into an object like the bottom plate of Fig. 1 or the pipe of Fig. 3a; and

Fig.8 shows a collection of images which may be displayed alone or in combination on a screen. The present invention is related to a phased array ultrasonic test system and method for inspecting various objects, such as, but not limited to, pipes and tanks – especially pipe on supports, annular and bottom plates of tanks.

The present invention can be applied to a wide variety of industrial equipment (including pipes). However, for convenience of description, the invention will be described herein as applied to the phased array ultrasonic inspection of pipe on supports, and annular plates of tanks.

As employed herein, the phrase “pipe on support” corresponds to one section of pipe on top of a support, or concealed by a support.

As employed herein, the phase “inaccessible part” means that one part of an object is not directly accessible, or easily accessible. For example, the pipe on a support cannot be accessible for visual inspection directly without lifting the pipe.

The present invention employs phased array ultrasonic inspection system which can comprise one single phased array transducer or two or more phased array transducers. Each of the transducer is typically made as a series of individual elements. These individual elements can be excited in various sequences that allow the ultrasonic beams generated therefrom to be shaped, angled or focused within the tested object. The phased array transducer and wedge are used to allow multiple angle beam inspection sweeps to be conducted consecutively without the need to use numerous individual wedges which is required in the conventional inspection. Referring now to Fig. 1 there is shown that an apparatus 300 used for inspection of a bottom plate of a tank 302 which is 10 mm thick. The apparatus 300 comprises a first phased array ultrasonic transducer 304 (combining a phased array transducer unit 306 a phased array wedge 312), a scanner 402 and an encoder 404 to record the position of the phased array transducer 304. The phased array ultrasonic transducer 304 is coupled to a receiver-transmitter 307.

When the phased array transducer 304 is excited, it generates a pulse of shear waves in the form of a beam 310 propagating in a direction θ from the normal. The pulse of shear waves (also referred to as a beam or wave beam) will reflect one or more reflections before being reflected back to the phased array transducer 304 by any discontinuity in the object, such as crack, corrosion, or edge of the bottom plate 302. The apparatus is designed so that it subsequently generates pulsed shear waves with mutually different values for the angle θ. In this manner a plurality of reflected signals can be received which comprise information about the volume of the bottom plate of the tank.

Thus when the phased array transducer unit 306 is excited, it generates a pulse of compression waves via the coupling wedge 312 of the transducer 304 into the bottom plate 302. This generally generates a pulse of shear waves or beam 310 propagating in a direction θ from the normal. The shear wave angles θ (comprising θ_1, $\theta_2 \ldots \theta_n$) in the plate generated by the transducer 304 are larger than the shear-compression critical angle, which easily cover the frequently-used angles (45°, 60° and 70°) in Multi Skip technique. When this pulse of shear waves 310 reaches the opposed surface 320 of the plate, it will reflect back as shear waves 312 without any mode conversion. And the pulse of shear waves 312 will reflect from the other surface 322 one or more times as shear wave 324 etc. Thus this implies multiple skips. This is also shown in Fig. 2d for one generated beam. These multiple skips provide the possibility to investigate areas of the plate which would normally not be accessible for conventional ultrasonic inspection methods using direct beams. If there would be corrosion 358 on position 150 this can be derived from the interaction of the waves with the corroded area. The waves would be reflected back towards the transducer and reach the transducer after having reflected at least one time on the surfaces 320 and 322. The reflected signals are received by the transducer 304.

In the method according to Fig. 1 the angles of shear waves (θ_1, $\theta_2 \ldots \theta_n$) will be varied in phased array sectorial scan. The wave paths are indicated by rays, but it will be understood that the transducer 304 will in fact emit a beam of finite width which will diverge slightly.

Each of the detected signals by means of the transducer 304 will be supplied to a computer 200 for processing in combination the received signals to provide an image of the internal of the object on a screen 220. The computer may be provided with special software for processing the detected signals such as commercially available as ISONIC 2010 Portable Ultrasonic Digital Flaw Detector and Recorder which does include both the computer and the software. The image may for example be in the form/format of a well known B-scan, C-scan or Sectorial scan. Thus although a B-scan, C-scan and Sectorial scan are actually not (completely) carried out, the way the information is presented on the screen may be in the format of such a scan. This is convenient for a user who is familiar in the interpretation of such scans. In the Sectorial scan the color indicated the amplitude at a position x on a depth d. In the B-scan the color indicated the amplitude at a position x on a depth corresponding with time t or alternatively in the B-scan the color indicated the amplitude at a position x on a depth d corresponding with time t and taking the beam angle θ into account. In the C-scan the color indicated the amplitude as seen on a top view of the product at a position (x,y). In Fig. 1 the direction of vector Y is perpendicular to the direction of vector d and vector x.

Fig. 2a and b shows images in the format of a B-scan and C-scan obtained using the apparatus 300 for inspection of a steel plate of thickness 12mm. To represent the effect of defects, 8 flat bottom holes had been machined in the upper surface, as shown in Table 1.

Table 1 Details of defects machined in the test plate

Defect No.	Defect Type	Diameter (mm)	Depth (mm)
D1	FBH	8	2
D2	FBH	8	5

D3	FBH	8	8
D4	FBH	8	10
D5	FBH	16	2
D6	FBH	16	5
D7	FBH	16	8
D8	FBH	16	10

The phased array probe was placed near one edge of the plate, 100 mm from the 8 mm flat bottom holes, and 290 mm from the 16 mm flat bottom holes. In Fig. 2a, Defects No. 1-4 are shown in the upper position from the left to the right, and Defects No. 5-8 are shown in the lower position from the left to the right. In Fig. 2B, Defects No. 1-4 are shown in the lower position from the left to the right, and Defects No. 5-8 are shown in the upper position from the left to the right. It can be evidently observed that all flat bottom holes are detected with correct positions. And the signals from the far end of the plate are disappeared or weakened due to the existence of defects.

Fig. 2C shows an example of an image generated by the computer 200 in the format of a sectorial scan of a defect obtained using the apparatus 300 for inspection of a steel plate.

Fig. 3a shows an apparatus 100 used for inspection of a steel pipe 102 which is 20 mm thick. The pipe rests on a support 120. Thus positions in the pipe above the support are not accessible for conventional methods wherein ultrasonic transducers are used. The apparatus 100 includes a first phased array ultrasonic transducer 104 (combining a phased array transducer unit 106 with a phased array wedge 112) and optionally a second phased array ultrasonic transducer 104'(combining a second phased array transducer unit 106' with a phased array wedge 112') , separated by a distance of 1000 mm along the pipe 102 from the first phased array transducer 104.The first phased array ultrasonic transducer 104 is connected to a transmitter-receiver 107 and the second phased array ultrasonic transducer 104'is connected to a receiver 107'.The transmitter-receiver 107 and the receiver 107' are connected to a computer 200. And the apparatus also includes a scanner 202 used to keep the probe distance constant and an encoder 204 to record the position of phased array transducers.

When the phased array ultrasonic transducer unit 106 of the transducer 104 is excited by means of the transmitter-receiver 107, it generates a pulse of compression waves in the coupling wedge 112. This generally generates a pulse of shear waves 116 propagating in a direction θ from the normal. The shear wave angles θ (comprising θ_1, $\theta_2 \ldots \theta_n$) in the pipe generated by the transducer 104 are larger than the shear-compression critical angle, which easily cover the frequently-used angles (45°, 60° and 70°) in Multi Skip technique. When this pulse of shear waves 116 reaches the apposed surface of the pipe, it will reflect back as shear waves 118 without any mode conversion. And the pulse of shear waves will reflect from the surfaces one or more times before being received by the second phased array ultrasonic transducer 104'. Thus this implies multiple skips. These multiple skips provide the possibility to investigate areas of the plate which would normally not be accessible by conventional ultrasonic inspection methods. If there would be corrosion on position 150 this can be derived form the interaction of the waves with the corroded area.

Each of the signals detected by means of the second phased array ultrasonic transducer 104' and the receiver 107' is submitted to the computer 200. The computer processes this detected signals in combination for creating an image on a screen 220 of the detected object. The computer 200 may be provided with special software for processing the detected signals such as commercially available as ISONIC 2010 Portable Ultrasonic Digital Flaw Detector and Recorder which does include both the computer and the software. The image may for example be in the form of a well known B-scan, C-scan or Sectorial scan. An example if the Sectorial scan is shown in Fig.3b.Thus although a B-scan, C-scan and Sectorial scan are actually not (fully) carried out, the way the information is presented on the screen may be in the format of such a scan. This is convenient for a user who is familiar in the interpretation of such scans.

In Fig 3a the angles of shear waves (θ_1, $\theta_2 \ldots \theta_n$) will be varied in phased array sectorial scan, and kept the same in phased array linear scan. The wave paths are indicated by rays, but it will be understood that the phased array ultrasonic transducer 104 will in fact emit a beam of finite width which will diverge slightly.

It is also possible to receive waves, which are reflected back, for example due to the corrosion, by means of the first phased array ultrasonic transducer 104. Thus the first phased array ultrasonic transducer 104 can also be used in combination with the transmitter-receiver 107 for receiving the reflected waves. The waves which are thus received by means of the transmitter-receiver 107 can also be submitted to the computer 200 for processing these detected signals in combination for creating an image on a screen 220 of the detected object. In that case the receiver 106' could be deleted.

In Fig. 1 and Fig. 3a, no welds are shown in the pipe 102 and plate 302, but it does not indicate that the present invention cannot test objects with welds. On the contrary, it is shown in experiments that an object with a weld between the transmitter and receiver phased array transducers or in front of the single phased array transducer can be tested by the present invention.

For each of the examples provided and also in general for a method according to the invention the inaccessible part of a pipe or plate is inspected by coupling an ultrasonic transmitter phased array transducer to an accessible surface of the tested object to emit an angled shear wave ultrasound beam propagating in a direction that is inclined from the normal to the surface. The ultrasonic beam reflects on the opposite surface of the object back to the surface where the transducer is positioned, this is referred to as skip. Using multiple skips allows for examination of an area further away and not directly accessible for positioning the transducer itself, like near a pipe support or beyond a tank shell.

Instead of using a conventional transducer with a fixed beam direction, a phased array transducer is used connected to a phased array system. This allows for steering the ultrasonic beam in various beam angles as known to the person skilled in the art. Using various beam angles ensures better coverage of the complete wall thickness and makes the examination less dependent on the shape and orientation of the corrosion because each part of the corrosion surface is hit by ultrasound beams at various angles.

For tank base plate condition assessment only the part 370 in Fig. 1 of the tank base plate (extending outside the tank wall) can be examined with conventional direct beams, for example with 0° beams as used for wall thickness measurement. However, also other parts at the underside of the bottom plate are susceptible to corrosion due to water ingress under the tank, like the area 372 directly under the tank wall 350 or the area 374 located inside of the tank wall.

For tank base plate condition assessment as discussed for Fig 1. the new approach enables using one phased array transducer to evaluate different parts that are not directly accessible: area 372 located directly under the tank wall 350, inspect the fillet welds 354, 356 that connect the tank wall to the tank base plate, and provide imaging into the tank base plate, and detect corrosion 358 for example on location 150. This system is designed to inspect locally and deep into a storage tank base – this is normally carried out with LORUS (Long Range Ultrasonics), using conventional transducers with fixed beam angles.

A vertical wall of the tank 350 (shell) is welded to the tank floor plate 302. In the tank base inspection the transducer is positioned on the tank base plate outside the tank shell and the ultrasonic beam is directed into the tank floor plate beyond the vertical tank shell. Suitable angles are selected to inspect the fillet welds (between the shell and base plates) and shallower angles to inspect well inside the tank floor plate. The beam may be swinged to perform four inspections:

1- Straight beam thickness measurement on the outside part of the storage tank bottom plate, using compression waves (θ=0) wherein no multiple skip is used.

2- Steep Sectorial scan inspection of the first fillet weld, using shear waves (θ is varied between θ_1 and θ_2 wherein a single skip is used. One example for a value of θ is shown in Fig. 4.

3- Less steep Sectorial scan to inspect the second fillet weld, using shear waves (θ is varied around $\theta_{3)}$ wherein a single skip is used. One example for a value of θ is shown in Fig. 5.

4- Shallow angle to inspect deep into the tank base (using shallow angle sectorial or linear scans), using shear waves (θ is varied between θ_3 and almost 90 degrees) wherein multiple skip is used. Fig. 6 shows a typical scan plan using three skips. Fig. 7 shows the image on the display corrected for the skips (true geometry).

The focus is the ability using one Phased Array transducer to undertake tank base plate condition assessment. The drive here is the look at the water ingress / corrosion directly under the tank wall, inspect the fillet welds and provide imaging into the tank base plate. The method according to the invention has provided excellent results for both the localized weld inspection as well as the long range phased array inspection. For Annular plate inspection it is preferred to use the back wall 360 (far edge, see Fig. 1) of the plate as a reference.

In this inspection shear wave angled beams are used in a pulse echo way. Depending on the situation a plate bulk wave can be used. In certain situations not only the above referred to angled compression wave beams can be used but also creep wave or surface wave (wherein θ = 90 degrees) could be used. These angled compression wave beams are generated if the shear wave angled beam is at or below the critical angle (Snell's law), as known to the person skilled in the art.

The above examples for Fig. 1 and Fig. 3a describes the examination while the transducer is in a static (fixed) position wherein θ is varied by means of the phased array transducer and multiple skip is applied. In addition if θ = 0 degrees a thickness measurement can be carried out and if θ = 90 degrees an inspection using creep waves could be carried out.

Alternatively the examination is performed while the transducer is moved sideways in the direction of the arrow y in Fig. 1 and in a tangential direction of the pipe in Fig. 3a. (thus compared to the direction of the ultrasonic beam) to scan the object, e.g. moving the transducer along the tank bottom plate or around the pipe. An encoder is used to record the position/movement of the transducer and store this information together with the ultrasonic results. The receiving signals obtained are again submitted to the computer for processing in combination and generating an image as shown in Fig. 8. In that case also multiple skip will be applied as is schematically shown in Fig. 2d.

Also for the examination of the bottom plate as shown in Fig 1 or the pipe on supports as shown in Fig. 3a, more information of the corrosion can be obtained while the transducer is at one position if the ultrasonic beams are entered into the object at different positions at the surface. This can be done by activating other elements of the transducer unit 106 or 306, also known as linear scan in phased array technology. Fig. 2e shows the result of such a linear scan for the embodiment of Fig. 1. In addition even more information of the corrosion can be obtained if the transducer is moved towards or away /from the area under examination, in the direction of the ultrasound beam, typically in axial direction x of a pipe when examining a pipe on a support or in a direction perpendicular to a side wall of a tank when examining a bottom plate of the tank. This direction is indicated with x in Fig. 1 and Fig.3a. Thus the position of the transducer is varied in a direction from the transducer to a zone 358 of the object to be inspected, thus in a direction of the component of the beam along the surface of the object whereon the transducer is positioned. Using an encoder and suitable software known as such allows for a geometric reconstruction of the area under examination, consisting of multiple overlayed Sectorial scans based on various transducer positions, as shown in Fig. 3b.

The results of the various beam angles in the sectorial scan or linear are combined into one overview for evaluation. For evaluation the measured amplitudes can be shown in the format of a C-scan (a top view), B-scan (a side view) or Sectorial scan (a side view). In each of such scans the color represents an amplitude of the wave received from a certain position or area. Thus, the evaluation is amplitude based. From the B/C scan the dimensions of the corrosion can be determined (length, width, depth). Please note that a B-scan can be obtained by moving the transducer (an actual scan) or by using different elements, at different positions, of the phased array transducer. In the present invention a sectorial scan and/or linear scan is actually carried out and the results are shown in the format of B–scan and/or C-scan and/or Sectorial scan and/or even a D-scan if desired. The received signal in the form of an A-scan (Fig. 8; 8.1), the generated format of a B-scan (Fig. 8; 8.2; note the vertical axes denoted t (time) or d (depth)), the generated format of a C-scan (Fig. 8; 8.3) and/or the generated format of a Sectorial or Linear scan (Fig. 8; 8.4) can be generated by the computer 200 and shown as an image on the screen 220 alone or in combination.

For the side view display (B-scan) the measured signals can be displayed uncorrected for the skips (see Fig. 2c) (typical Sectorial-scan display). The software of the computer 200 is capable to correct the signals for the reflections at the objects (skips), so called true geometry (see Fig. 7). In the corrected or uncorrected side view the depth/height of an indication (corrosion) can be measured using the amplitudes of the signals, e.g. -6 dB method. Some software provides statistical analysis of the data, for example a histogram, that support the evaluation of the depth/height of an indication. This software is known as such and described on page 352 and 373 of the manual ISONIC 2005 / 2010/ STAR, showing the histogram/statistical function, and stating that the histogram represents the occurrence of 'informative parameter (amplitude or distance) represented by colors in the area of polygon; statistical distribution is presented by appropriate graph.

Several phased array possibilities can be used (pitch-catch, electronic scanning, sectorial scanning, dynamic depth focusing) depending on the geometry (thickness of the plate, length to be examined, transducer position) and is taken into account by the measuring and display software.

The ultrasonic examination can be carried out using an ultrasonic testing technique consisting of pulse-echo, pitch-catch, electronic scanning, linear or sectorial scanning, dynamic depth focusing, and a combination of thereof and a transmitting phased array transducer and a receiving phased array transducer may be used, separated by some distance and or a single phased array transducer can be used. The method can be used in plates, pipes, tanks, vessels, etc. The phased array ultrasonic transducer mentioned may include 1-D, 1.5-D and 2-D arrangements.

Conclusies

1. Een werkwijze voor het inspecteren van een voorwerp (102), waarbij de werkwijze de volgende stappen omvat:

a. het koppelen van een eerste phased array ultrasone omzetter (104) aan een eerste oppervlak van het voorwerp;

b. het uitzenden van een ultrasone golf door middel van de omzetter in het voorwerp onder een eerste hoek ten opzichte van een normaal van het eerste oppervlak op de positie van de omzetter zodat de golf zich voortplant in het voorwerp tussen het eerste oppervlak van het voorwerp en een tweede oppervlak van het voorwerp terwijl in successie ten minste een keer te worden gereflecteerd in het voorwerp op het tweede oppervlak en het eerste oppervlak respectievelijk, zogenoemde multiple skip en het detecteren van de golf die zich voortplant door het voorwerp;

c. het ten minste een keer herhalen van stap b. voor een andere hoek dan de eerste hoek en/of een andere omzetterpositie waarbij de positie van de omzetter wordt gevarieerd in een richting x langs het eerste oppervlak van de omzetter naar een gebied van het te inspecteren voorwerp en/of in een richting langs het oppervlak loodrecht op de richting x;

d. het combineren van de gedetecteerde golven en het tot stand brengen op basis van de gecombineerde gedetecteerde golven van een beeld dat ten minste een eerste deel van het binnenvolume van het voorwerp vertegenwoordigt op een scherm waarbij het ten minste eerste deel van het binnenvolume correspondeert met een positie welke offset is ten opzichte van de normaal.

2. Werkwijze volgens conclusie 1, waarbij stap c. een veelvoud van keren wordt herhaald voor onderling verschillende hoeken respectievelijk en/of voor een veelvoud van onderling verschillende omzetterposities respectievelijk.

3. Werkwijze volgens een der voorgaande conclusies waarbij de omzetterpositie wordt gevarieerd in stap c. waarbij in stap d. het combineren van de gedetecteerde golven voor het tot stand te brengen van het beeld ook wordt gebaseerd op de posities van de omzetter opgenomen door een encoder.

4. Werkwijze volgens conclusie 3, waarbij de omzetterpositie wordt gevarieerd in een richting loodrecht op de richting waarin uitgezonden golven zich voortplanten door het voorwerp.

5. Werkwijze volgens conclusie 1, 2, 3, of 4, waarbij in stap d. een beeld wordt gecreëerd in het format van een B-scan, C-scan, D-scan en/of Sectorial scan.

6. Werkwijze volgens een der voorgaande conclusies, waarbij de golf wordt gedetecteerd door middel van de eerste phased array ultrasone omzetter.

7. Werkwijze volgens een der voorgaande conclusies 1-5, waarbij de golf wordt gedetecteerd door middel van een tweede phased array ultrasone omzetter welk ook gekoppeld is aan een oppervlak van het voorwerp op andere positie dan de eerste phased array ultrasone omzetter.

8. Werkwijze volgens een der voorgaande conclusies, waarbij het voorwerp een bodem van een tank is waarbij de eerste phased array ultrasone omzetter wordt gekoppeld aan het eerste oppervlak van het voorwerp buiten de tank en waarbij het eerste deel van het volume ligt onder een binnenruimte van de tank.

9. Werkwijze volgens eender voorgaande conclusies waarbij het voorwerp een pijplijn is die op een steun ligt waarbij het eerste deel van het volume boven de steun ligt.

10. Werkwijze volgens conclusie 9, waarbij de eerste phased array ultrasone omzetter wordt gekoppeld aan het eerste voorwerp op een longitudinale positie van de pijplijn welke offset is ten opzichte van de steun.

11. Werkwijze volgens conclusie 6 en/of 7 en conclusie 8 of 9.

12. Werkwijze volgens een der voorgaande conclusies waarbij een reflectie op een eindoppervlak welk het eerste en tweede oppervlak verbindt, gedetecteerd wordt en waarbij een relatief lage intensiteit van zulke gedetecteerde reflectie een defect aanwijst langs het pad waarin de golf zich verplaatste in het voorwerp.

13. Werkwijze volgens een der voorgaand conclusies, waarbij corrosie wordt gedetecteerd in het eerste deel op basis van reflecties van de golf op een gecorrodeerd gebied in het eerste deel.

14. Werkwijze volgens een der voorgaande conclusies, waarbij de uitgezonde straal een shear golfstraal is.

15. Werkwijze volgens een der voorgaande conclusies, waarbij de weergegeven scan wordt gecorrigeerd voor de reflecties aan het tweede en eerste oppervlak om de signalen op hun ware posities te projecteren.

16. Werkwijze volgens een der voorgaande conclusies, waarbij de diepte van de corrosie en/of overblijvende dikte wordt bepaald uit het beeld.

17. Werkwijze volgens een der voorgaande conclusies waarbij een statistisch analyse wordt uitgevoerd op het beeld om een afstand tussen indicaties en het eerste of tweede oppervlak te bepalen.

18. Systeem voorzien van ten minste een phased array omzetter, een computer en een scherm voor het uitvoeren van de werkwijze volgens een der voorgaande conclusies.

Fig. 1

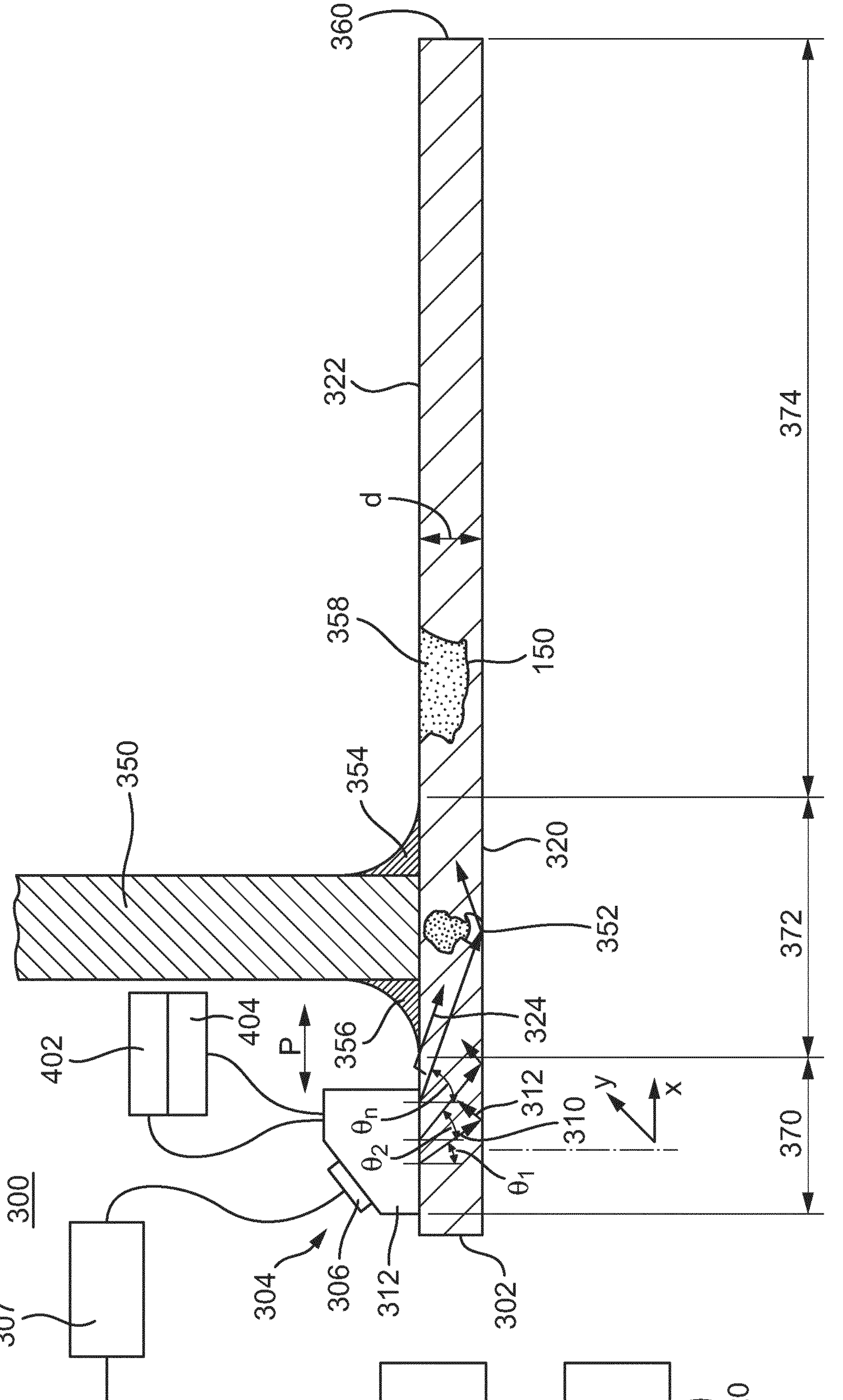
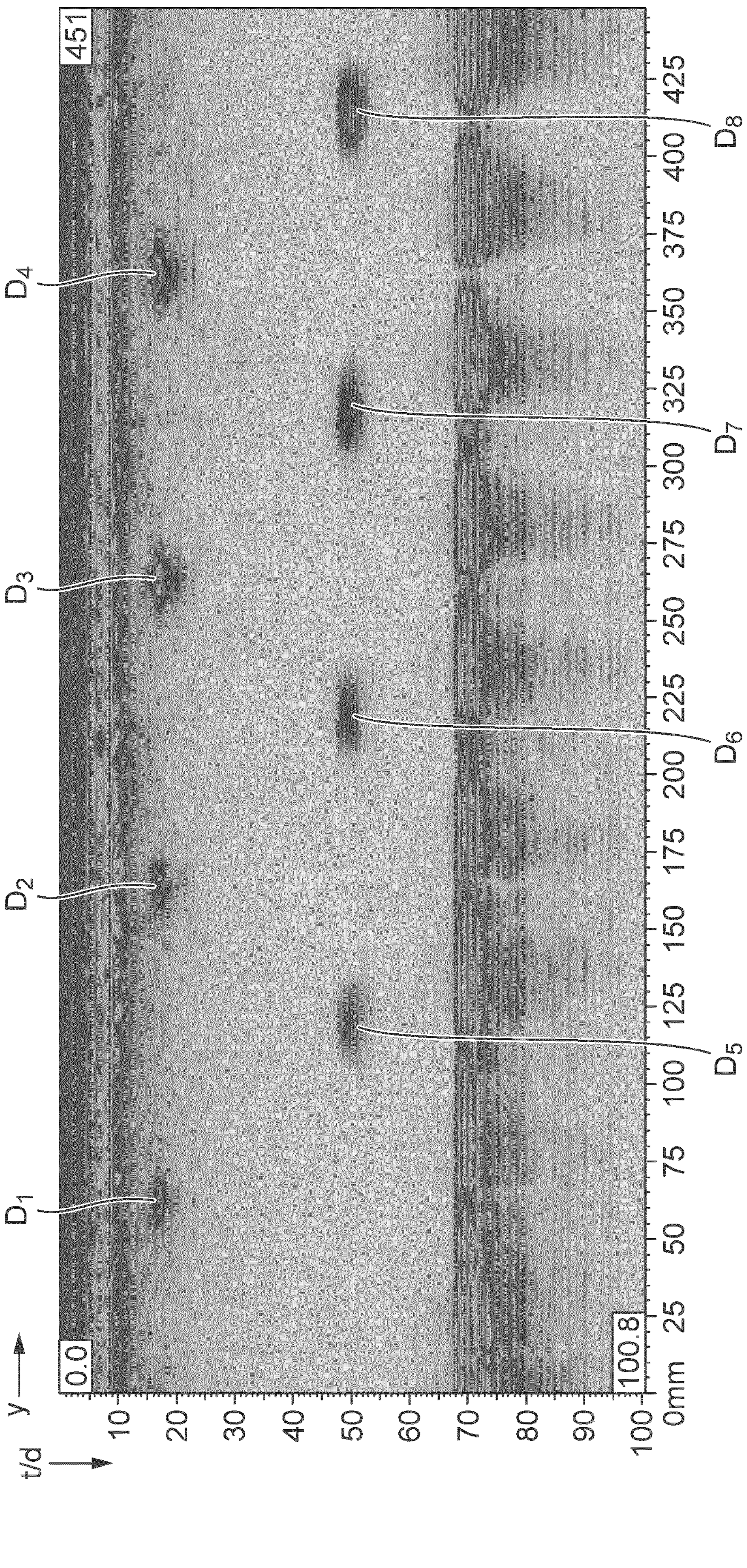

300
307
200
220
304
306
312
302
402
404
P
356
324
312
310
θ_1
θ_2
θ_n
y
x
370
372
374
352
320
350
354
358
150
d
322
360

Fig. 2a



D1
D2
D3
D4
D5
D6
D7
D8
t/d
y
0.0
100.8
451
0mm
10
20
30
40
50
60
70
80
90
100
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
400
425

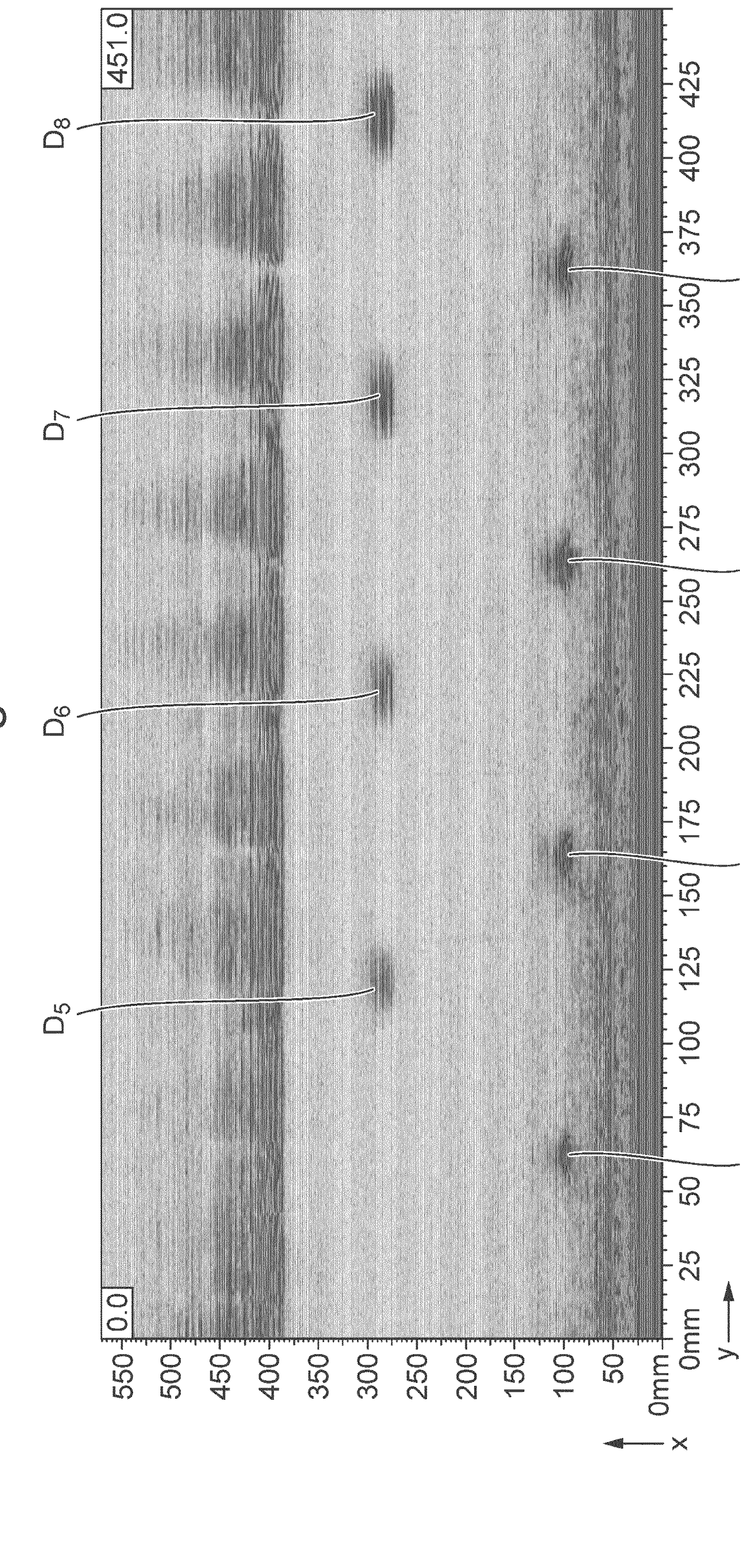

D5
D6
D7
D8
D1
D2
D3
D4
0.0
451.0
x
y
0mm
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
400
425
50
100
150
200
250
300
350
400
450
500
550

Fig. 2b

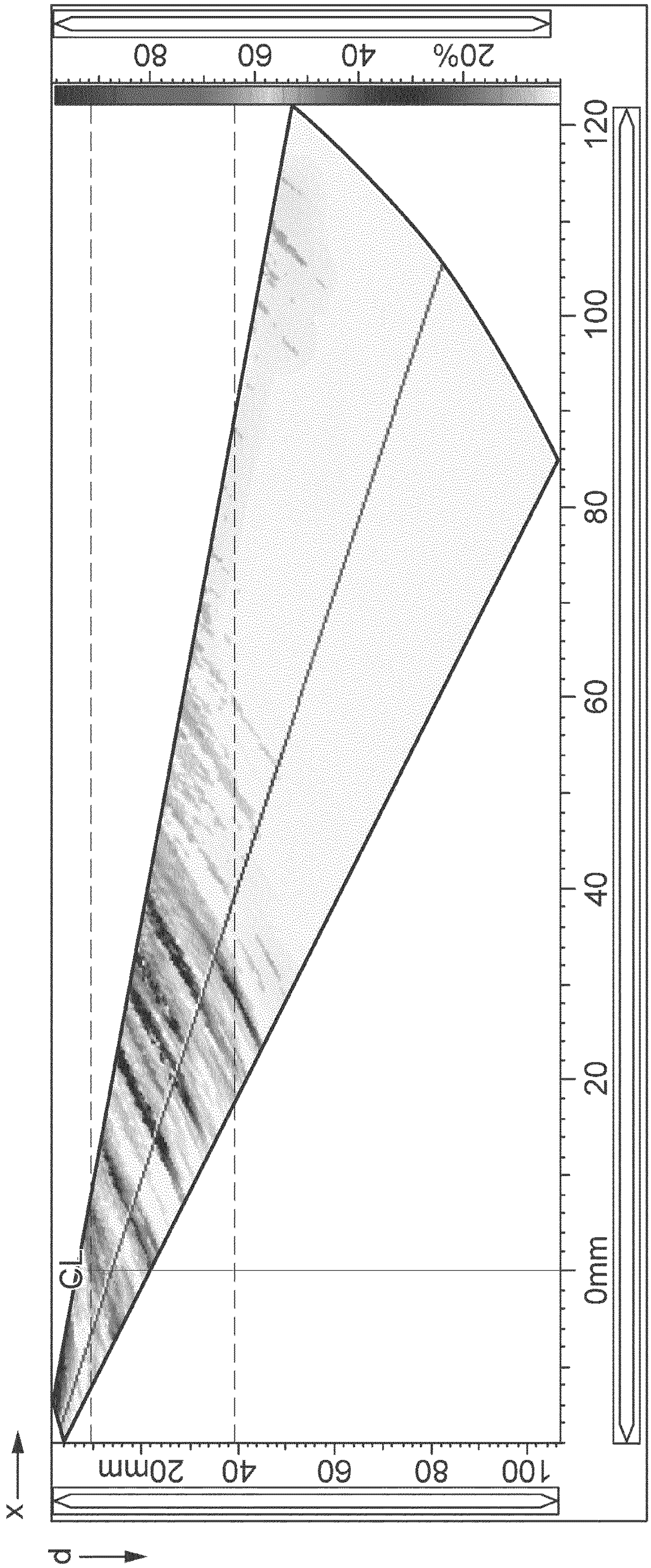


Fig. 2c

Fig. 2d

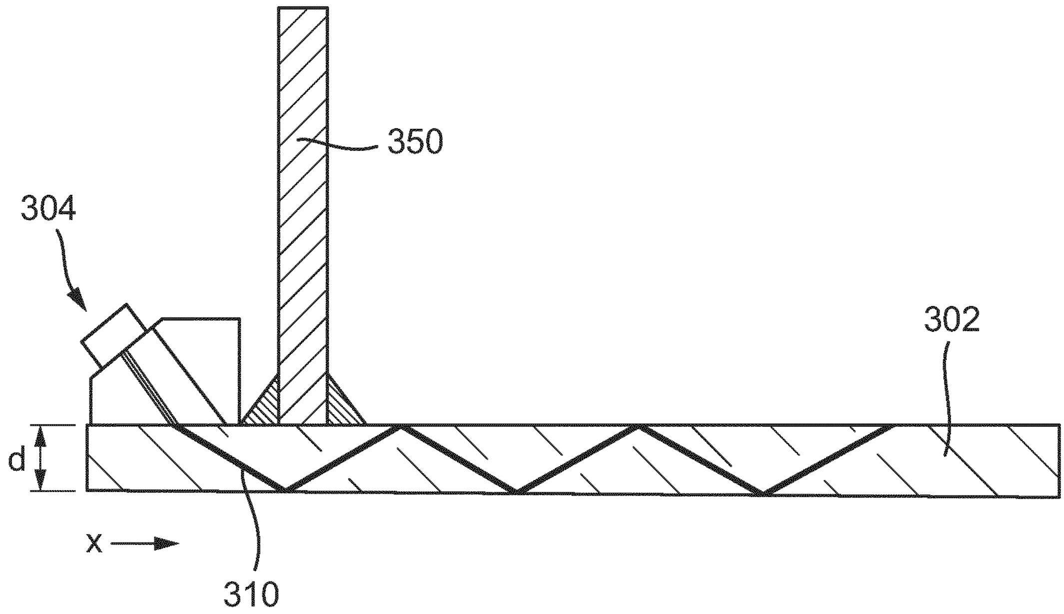


Fig. 2e

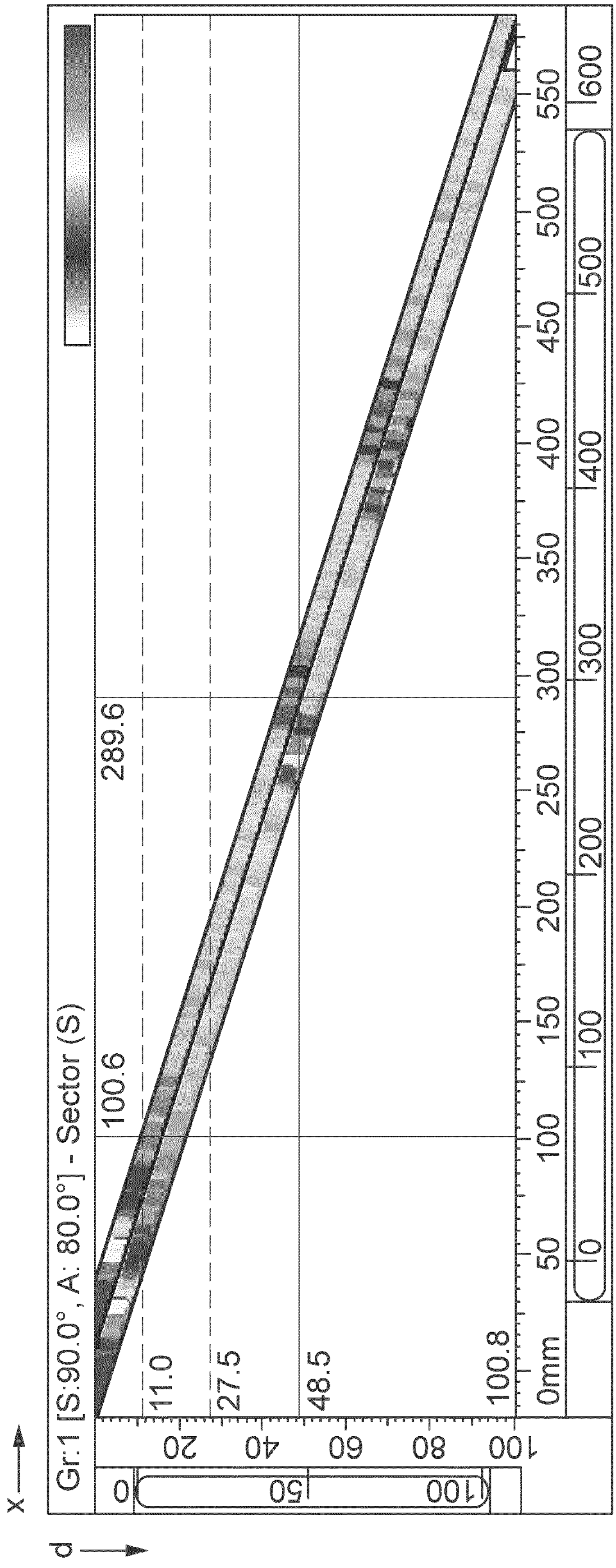
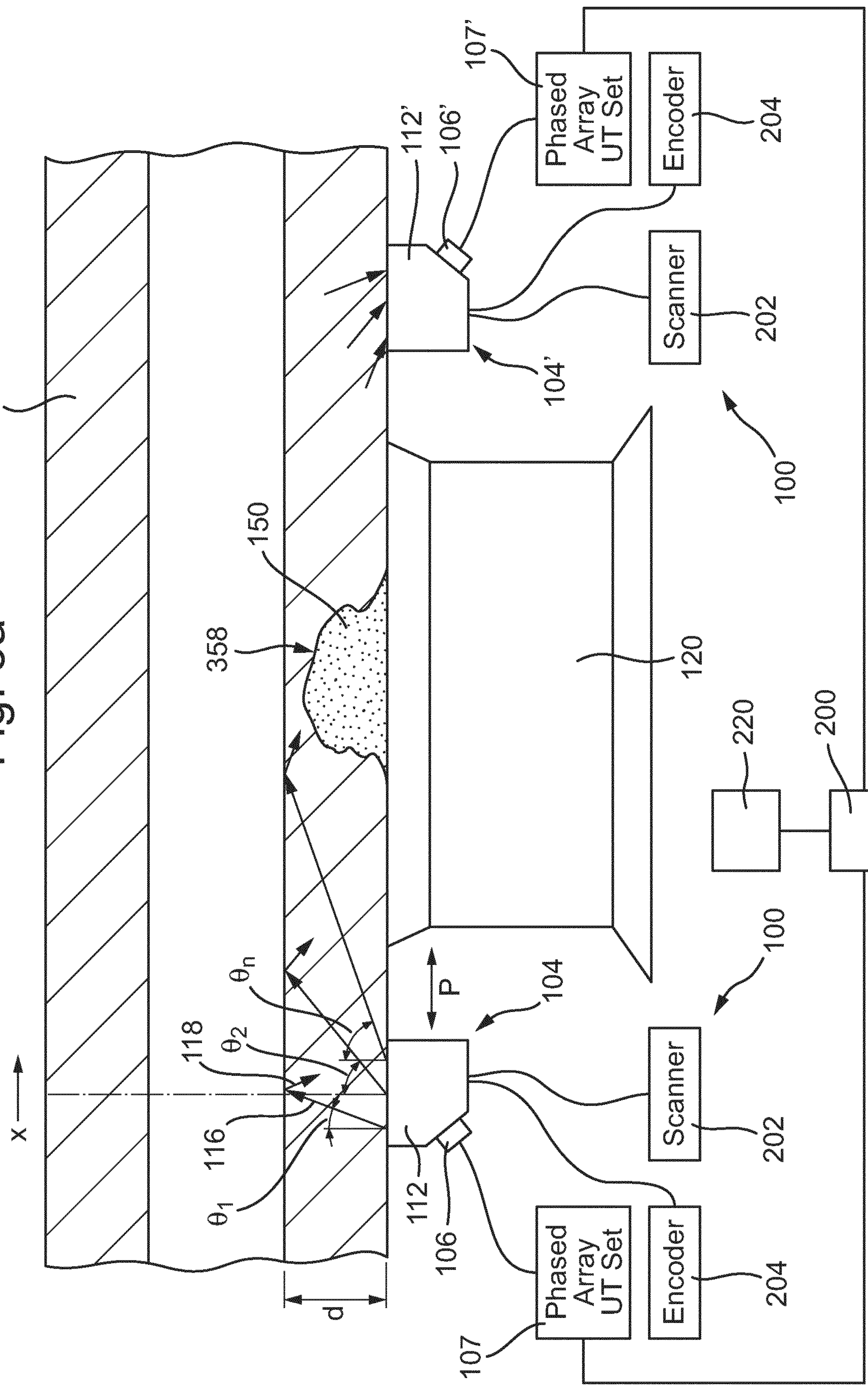

Gr:1 [S:90.0°, A: 80.0°] - Sector (S)
100.6
289.6
11.0
27.5
48.5
100.8
0mm
50
100
150
200
250
300
350
400
450
500
550
0
100
200
300
400
500
600
20
40
60
80
100
0
50
100
x
d

Fig. 3a



102
358
150
120
112'
106'
107'
Phased Array UT Set
Encoder
204
Scanner
202
104'
100
220
200
104
P
θn
θ2
118
116
θ1
x
112
106
d
107
Phased Array UT Set
Encoder
204
Scanner
202
100

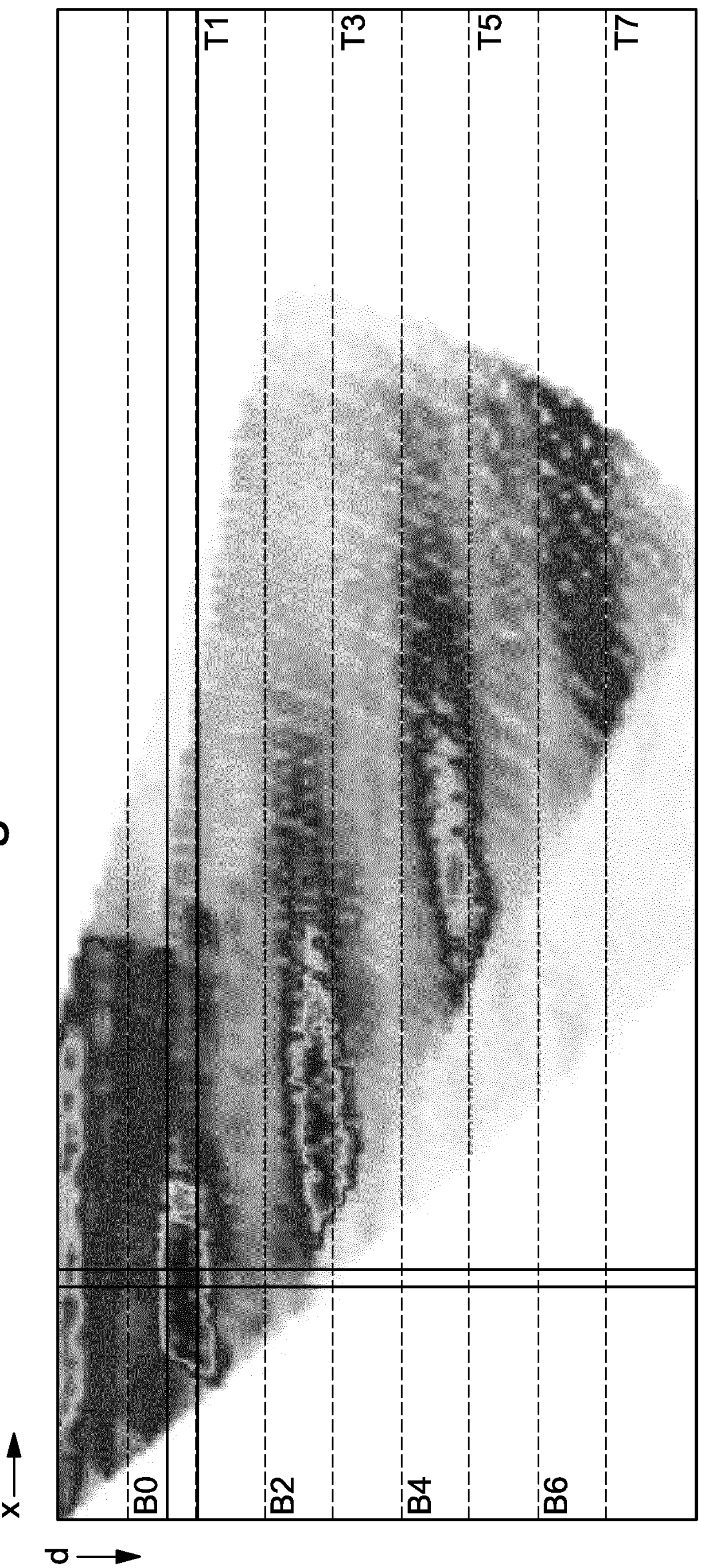


Fig. 3b

Fig. 4

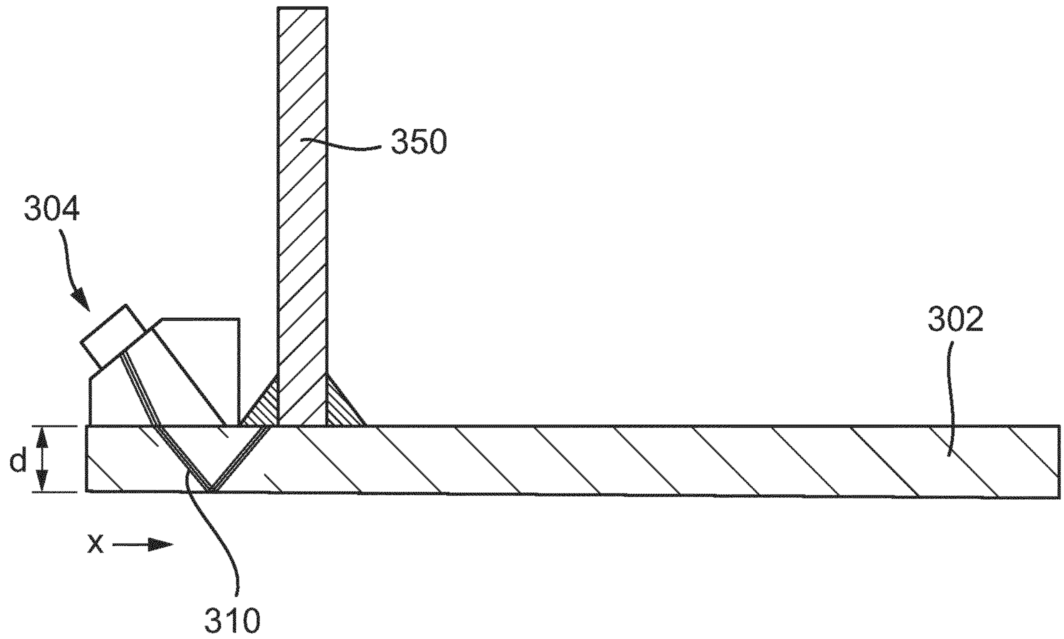


Fig. 5

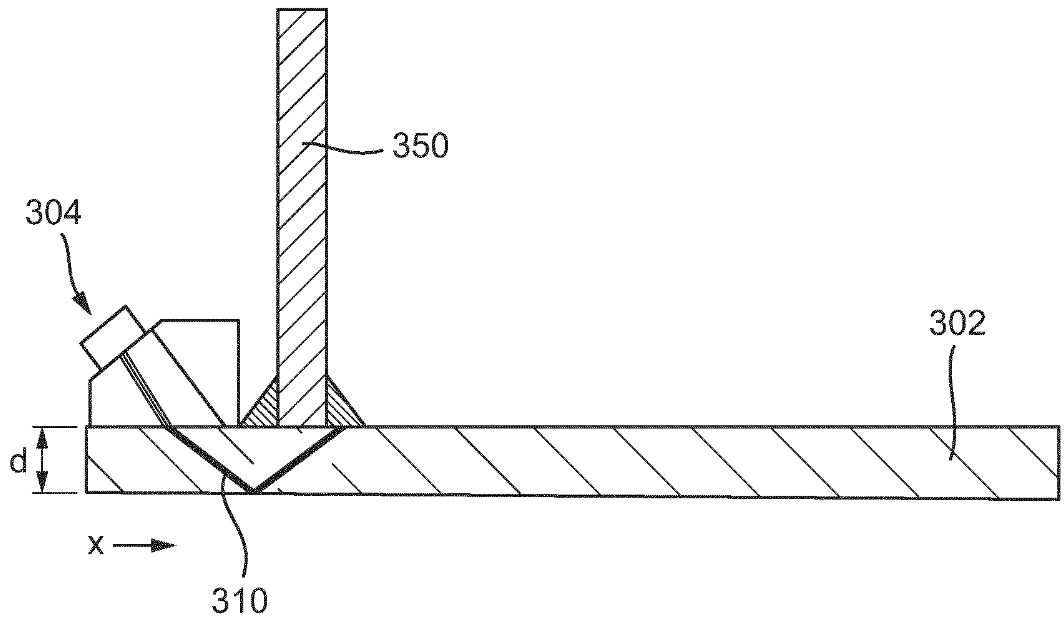


Fig. 6

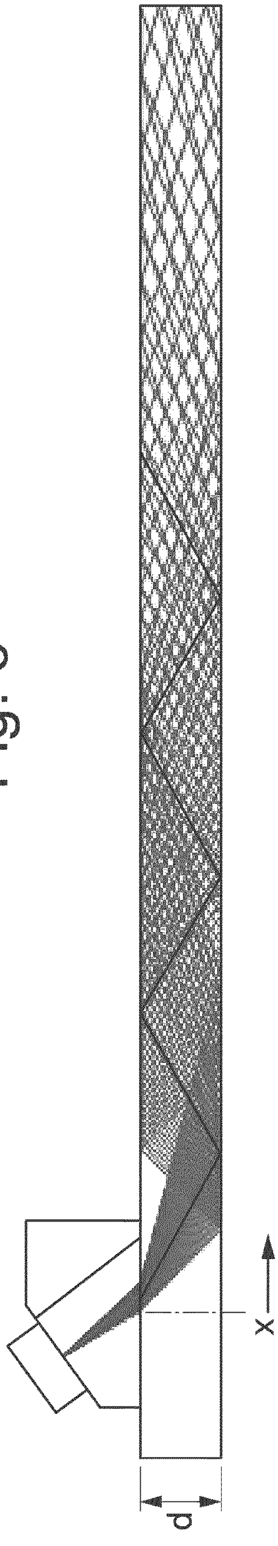


Fig. 7

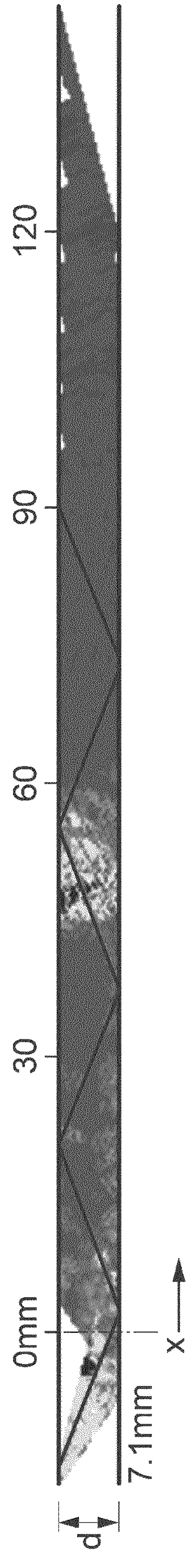
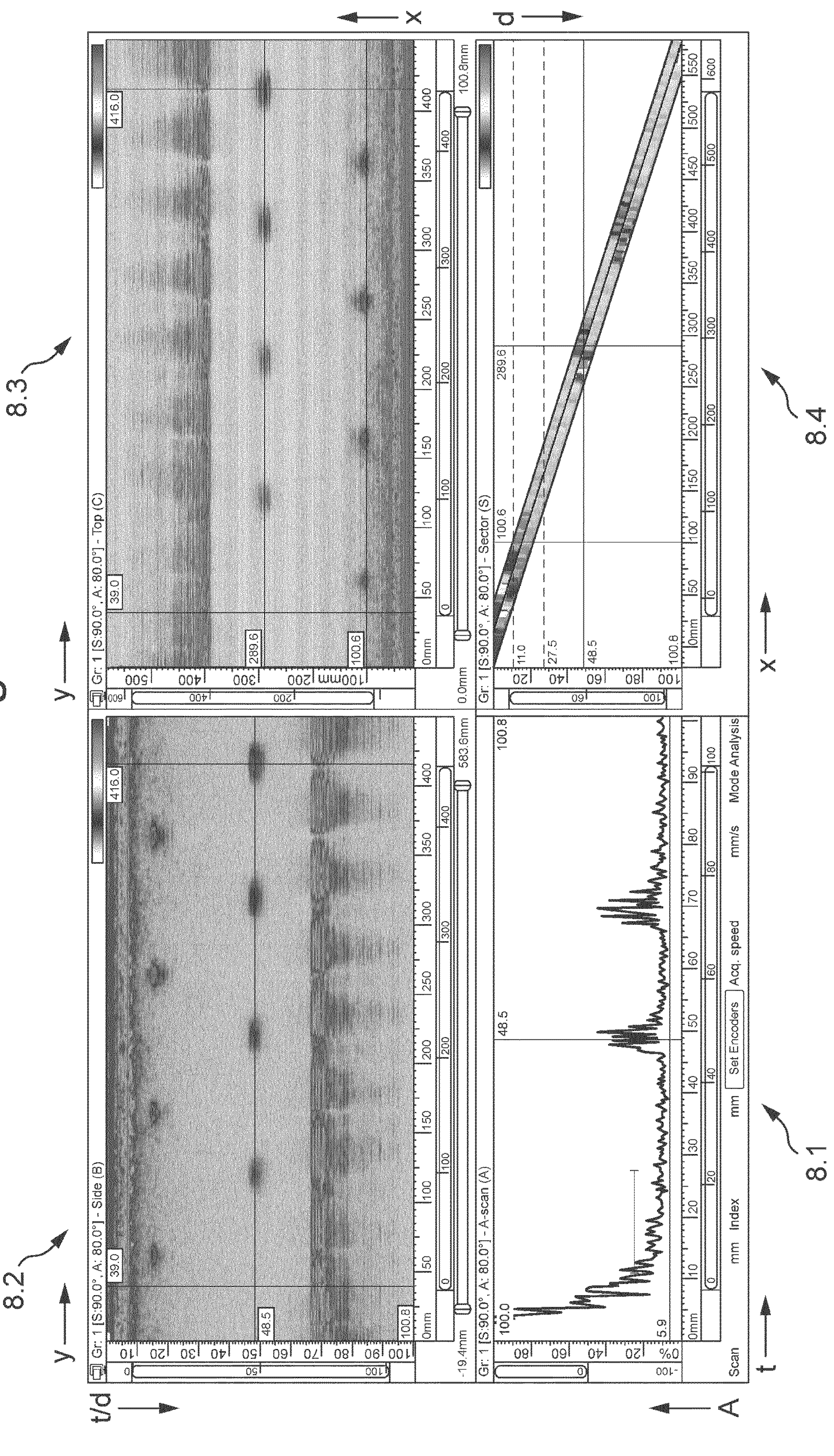


Fig. 8


8.1
8.2
8.3
8.4
t/d
y
x
d
A
t
Gr: 1 [S:90.0°, A: 80.0°] - Side (B)
Gr: 1 [S:90.0°, A: 80.0°] - Top (C)
Gr: 1 [S:90.0°, A: 80.0°] - A-scan (A)
Gr: 1 [S:90.0°, A: 80.0°] - Sector (S)
Scan
Index
mm
Set Encoders
Acq. speed
mm/s
Mode Analysis

SAMENWERKINGSVERDRAG (PCT)

RAPPORT BETREFFENDE NIEUWHEIDSONDERZOEK VAN INTERNATIONAAL TYPE

IDENTIFICATIE VAN DE NATIONALE AANVRAGE	**KENMERK VAN DE AANVRAGER OF VAN DE GEMACHTIGDE** **P103710NL00**
Nederlands aanvraag nr. **2012363**	Indieningsdatum **05-03-2014**
	Ingeroepen voorrangsdatum
Aanvrager (Naam) **Röntgen Technische Dienst B.V.**	
Datum van het verzoek voor een onderzoek van internationaal type **19-04-2014**	Door de Instantie voor Internationaal Onderzoek aan het verzoek voor een onderzoek van internationaal type toegekend nr. **SN61839**

I. CLASSIFICATIE VAN HET ONDERWERP (bij toepassing van verschillende classificaties, alle classificatiesymbolen opgeven)	
Volgens de internationale classificatie (IPC) **G01N29/06;G01N29/22;G01N29/26**	
II. ONDERZOCHTE GEBIEDEN VAN DE TECHNIEK	
Onderzochte minimumdocumentatie	
Classificatiesysteem	Classificatiesymbolen
IPC	**G01N**
Onderzochte andere documentatie dan de minimum documentatie, voor zover dergelijke documenten in de onderzochte gebieden zijn opgenomen	
III. ☐ **GEEN ONDERZOEK MOGELIJK VOOR BEPAALDE CONCLUSIES**	(opmerkingen op aanvullingsblad)
IV. ☐ **GEBREK AAN EENHEID VAN UITVINDING**	(opmerkingen op aanvullingsblad)

Form PCT/ISA 201 A (11/2000)

ONDERZOEKSRAPPORT BETREFFENDE HET RESULTAAT VAN HET ONDERZOEK NAAR DE STAND VAN DE TECHNIEK VAN HET INTERNATIONALE TYPE

Nummer van het verzoek om een onderzoek naar de stand van de techniek
NL 2012363

A. CLASSIFICATIE VAN HET ONDERWERP
INV. G01N29/06 G01N29/22 G01N29/26
ADD.

Volgens de Internationale Classificatie van octrooien (IPC) of zowel volgens de nationale classificatie als volgens de IPC.

B. ONDERZOCHTE GEBIEDEN VAN DE TECHNIEK

Onderzochte miminum documentatie (classificatie gevolgd door classificatiesymbolen)
G01N

Onderzochte andere documentatie dan de mimimum documentatie, voor dergelijke documenten, voor zover dergelijke documenten in de onderzochte gebieden zijn opgenomen

Tijdens het onderzoek geraadpleegde elektronische gegevensbestanden (naam van de gegevensbestanden en, waar uitvoerbaar, gebruikte trefwoorden)

EPO-Internal, WPI Data

C. VAN BELANG GEACHTE DOCUMENTEN

Categorie °	Geciteerde documenten, eventueel met aanduiding van speciaal van belang zijnde passages	Van belang voor conclusie nr.
X	WO 2012/129703 A1 (ATOMIC ENERGY OF CANADA LTD [CA]; GAUDET MICHEL JOSEPH GILLES [CA]; LU) 4 oktober 2012 (2012-10-04) * samenvatting; figuren 1-12 * * alineas [0032] - [0091] * -----	1-18
X	US 2010/180683 A1 (LESAGE FREDERIC [FR] ET AL) 22 juli 2010 (2010-07-22) * samenvatting; figuren 1-11B * * alineas [0069] - [0103] * -----	1,18
A	US 2013/255384 A1 (PUTSHERRY DINESH DAMODAR [IN] ET AL) 3 oktober 2013 (2013-10-03) * samenvatting; figuren 1-7 * * alineas [0017] - [0030] * -----	1,18

☐ Verdere documenten worden vermeld in het vervolg van vak C.

☒ Leden van dezelfde octrooifamilie zijn vermeld in een bijlage

° Speciale categorieën van aangehaalde documenten

"A" niet tot de categorie X of Y behorende literatuur die de stand van de techniek beschrijft

"D" in de octrooiaanvrage vermeld

"E" eerdere octrooi(aanvrage), gepubliceerd op of na de indieningsdatum, waarin dezelfde uitvinding wordt beschreven

"L" om andere redenen vermelde literatuur

"O" niet-schriftelijke stand van de techniek

"P" tussen de voorrangsdatum en de indieningsdatum gepubliceerde literatuur

"T" na de indieningsdatum of de voorrangsdatum gepubliceerde literatuur die niet bezwarend is voor de octrooiaanvrage, maar wordt vermeld ter verheldering van de theorie of het principe dat ten grondslag ligt aan de uitvinding

"X" de conclusie wordt als niet nieuw of niet inventief beschouwd ten opzichte van deze literatuur

"Y" de conclusie wordt als niet inventief beschouwd ten opzichte van de combinatie van deze literatuur met andere geciteerde literatuur van dezelfde categorie, waarbij de combinatie voor de vakman voor de hand liggend wordt geacht

"&" lid van dezelfde octrooifamilie of overeenkomstige octrooipublicatie

Datum waarop het onderzoek naar de stand van de techniek van internationaal type werd voltooid	Verzenddatum van het rapport van het onderzoek naar de stand van de techniek van internationaal type
4 november 2014	

Naam en adres van de instantie	De bevoegde ambtenaar
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Uttenthaler, Erich

1

ONDERZOEKSRAPPORT BETREFFENDE HET RESULTAAT VAN HET ONDERZOEK NAAR DE STAND VAN DE TECHNIEK VAN HET INTERNATIONALE TYPE

Informatie over leden van dezelfde octrooifamilie

Nummer van het verzoek om een onderzoek naar de stand van de techniek

NL 2012363

In het rapport genoemd octrooigeschrift	Datum van publicatie	Overeenkomend(e) geschrift(en)	Datum van publicatie
WO 2012129703 A1	04-10-2012	CA 2831812 A1	04-10-2012
		EP 2691736 A1	05-02-2014
		US 2014076053 A1	20-03-2014
		WO 2012129703 A1	04-10-2012
US 2010180683 A1	22-07-2010	AR 067089 A1	30-09-2009
		AU 2008277580 A1	22-01-2009
		CA 2691213 A1	22-01-2009
		CL 2008001854 A1	26-12-2008
		CN 101765769 A	30-06-2010
		EG 26203 A	21-04-2013
		EP 2158478 A2	03-03-2010
		FR 2917833 A1	26-12-2008
		JP 5475654 B2	16-04-2014
		JP 2010530529 A	09-09-2010
		RU 2010101798 A	27-07-2011
		UA 100024 C2	12-11-2012
		US 2010180683 A1	22-07-2010
		WO 2009010654 A2	22-01-2009
		ZA 200909039 A	29-09-2010
US 2013255384 A1	03-10-2013	CN 103364490 A	23-10-2013
		SG 193693 A1	30-10-2013
		US 2013255384 A1	03-10-2013

WRITTEN OPINION

File No.	Filing date *(day/month/year)*	Priority date *(day/month/year)*	Application No.
SN61839	05.03.2014		NL2012363

International Patent Classification (IPC)
INV. G01N29/06 G01N29/22 G01N29/26

Applicant
Röntgen Technische Dienst B.V.

This opinion contains indications relating to the following items:

- ☒ Box No. I — Basis of the opinion
- ☐ Box No. II — Priority
- ☐ Box No. III — Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
- ☐ Box No. IV — Lack of unity of invention
- ☒ Box No. V — Reasoned statement with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
- ☐ Box No. VI — Certain documents cited
- ☒ Box No. VII — Certain defects in the application
- ☒ Box No. VIII — Certain observations on the application

	Examiner
	Uttenthaler, Erich

Application number

WRITTEN OPINION

NL2012363

Box No. I Basis of this opinion

1. This opinion has been established on the basis of the latest set of claims filed before the start of the search.
2. With regard to any **nucleotide and/or amino acid sequence** disclosed in the application and necessary to the claimed invention, this opinion has been established on the basis of:

   a. type of material:

   ☐ a sequence listing

   ☐ table(s) related to the sequence listing

   b. format of material:

   ☐ on paper

   ☐ in electronic form

   c. time of filing/furnishing:

   ☐ contained in the application as filed.

   ☐ filed together with the application in electronic form.

   ☐ furnished subsequently for the purposes of search.

3. ☐ In addition, in the case that more than one version or copy of a sequence listing and/or table relating thereto has been filed or furnished, the required statements that the information in the subsequent or additional copies is identical to that in the application as filed or does not go beyond the application as filed, as appropriate, were furnished.
4. Additional comments:

Box No. V Reasoned statement with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty	Yes:	Claims	3-17
	No:	Claims	1, 2, 18
Inventive step	Yes:	Claims	
	No:	Claims	1-18
Industrial applicability	Yes:	Claims	1-18
	No:	Claims	

2. Citations and explanations

   see separate sheet

WRITTEN OPINION

Box No. VII Certain defects in the application

see separate sheet

Box No. VIII Certain observations on the application

see separate sheet

Reference is made to the following documents:

D1 WO 2012/129703 A1 (ATOMIC ENERGY OF CANADA LTD [CA]; GAUDET MICHEL JOSEPH GILLES [CA]; LU) 4 oktober 2012 (2012-10-04)

D2 US 2010/180683 A1 (LESAGE FREDERIC [FR] ET AL) 22 juli 2010 (2010-07-22)

D3 US 2013/255384 A1 (PUTSHERRY DINESH DAMODAR [IN] ET AL) 3 oktober 2013 (2013-10-03)

Re Item V

Reasoned statement with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1 **Novelty and Inventive Step**

1.1 **Claim 1:**

Claim 1 does not appear to fulfill the requirements with respect to novelty:

D1 discloses a method for inspecting an object, the method comprising the following steps:

a. coupling a first transmitter phased array ultrasonic transducer (102, fig. 1, D1) to a first surface of the object (paragraphs 0032-0033, D1);

b. emitting by means of the transducer an ultrasonic wave into the object under a first angle relative to a normal of the first surface at the position of the transducer so that the wave propagates in the object between the first surface of the object and a second surface of the object while in succession being reflected in the object at the second surface and the first surface respectively multiple times, so called multiple skip and detecting the wave propagating through the object (paragraphs 0086-0087, D1);

c. repeating step b. at least one time for another angle than the first angle (paragraphs 0021 and 0083, D1);

d. combining the detected waves and producing based on the combined detected waves a image representing at least a first portion of the inner volume of the object on a screen wherein the first portion of the inner volume corresponds to a position which is offset relative to the normal (1114, fig. 11 and 1212, fig. 12 and paragraphs 0083 and 0091, D1).

Therefore, claim 1 is not novel.

Objections against an inventive step of claim 1 could have also been raised on the basis of document D2 (figs. 3, 7A-8C and paragraphs 0069-0103) .

1.2 **Claim 18:**

It appears that the above objections to claim 1 equally apply, mutatis mutandis, to the corresponding apparatus claim 18, in particular because the features are defined in terms of the functional features of claim 1.

Therefore, also claim 18 is also not novel.

1.3 **Dependent claims** :

The dependent claims appear to relate to mere conventional features or features already present in the arrangement of D1 or D2 and, therefore, do not appear to contain any additional features which, in combination with the features of any claim to which they refer, meet the requirements with respect to novelty and/or an inventive step.

Re Item VII

Certain defects in the international application

1 The prior art D1 and D2 is not identified in the description and the relevant background art disclosed therein not briefly discussed.

2 The features of the claims are partially not provided with reference signs placed in parentheses to increase the intelligibility of the claims.

Re Item VIII

Certain observations on the international application

Clarity

1 It is clear from the description on page 5, lines 12-25 and the figures that the feature of a scanner with an encoder is essential to the definition of the invention. It appears that the system of claim 18 can not perform the method steps as claimed in claim without this essential feature.

Since independent claim 18 does not contain this feature it does not meet the requirement of clarity that any independent claim must contain all the technical features essential to the definition of the invention.