(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
5 November 2009 (05.11.2009)

PCT

(10) International Publication Number
WO 2009/133384 A1

(51) International Patent Classification:
G01N 29/28 (2006.01) *G10K 11/02* (2006.01)

(21) International Application Number:
PCT/GB2009/050390

(22) International Filing Date:
20 April 2009 (20.04.2009)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
0807955.0 1 May 2008 (01.05.2008) GB

(71) Applicant *(for all designated States except US)*: **AIRBUS UK LIMITED** [GB/GB]; New Filton House, Bristol BS99 7AR (GB).

(72) Inventor; and

(75) Inventor/Applicant *(for US only)*: **COUSINS, John** [GB/GB]; AIRBUS UK LIMITED, New Filton House, Filton, Bristol BS99 7AR (GB).

(74) Agent: **BUTLER, Daniel**; Building 09A, Filton, Bristol BS99 7AR (GB).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

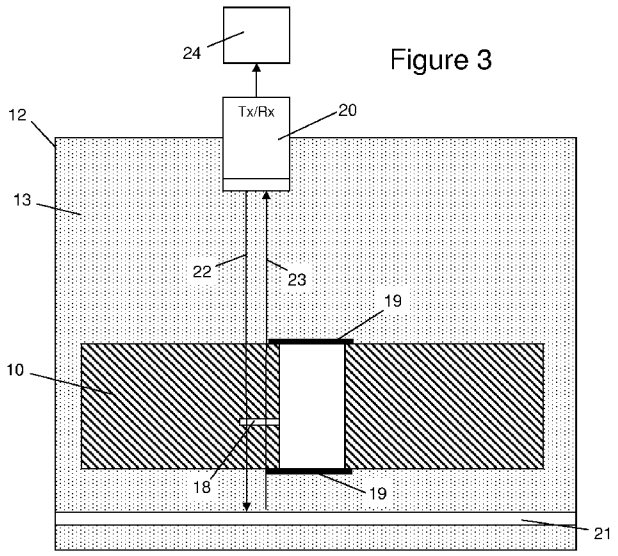
(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

(54) Title: ULTRASOUND INSPECTION METHOD AND APPARATUS

Figure 3



(57) Abstract: A method of inspecting a component, the component comprising a hole with an entrance. The method comprises: directing ultrasound into the component via a liquid coupling medium; receiving ultrasound from the component via the liquid coupling medium; and processing the received ultrasound to determine a propertyofthe component. The entrance of the hole is sealed with tape to prevent the liquid coupling medium from flowing into the entrance of the hole. The tape has an acoustic impedance within 40% of the acoustic impedance of the liquid coupling medium. By selecting a tape with an acoustic impedance relatively close to that of the liquid coupling medium (which in most cases will be water) the tape is relatively transparent to ultrasound and thus enables at least the presence or absence of a defect in a wall of the hole to be determined.

WO 2009/133384 A1

ULTRASOUND INSPECTION METHOD AND APPARATUS

FIELD OF THE INVENTION

The present invention relates to a method and apparatus for inspecting a component with ultrasound.

BACKGROUND OF THE INVENTION

Figure 1 shows a conventional method of inspecting a composite component 1 with a hole 2. The component 1 is immersed in a tank 3 containing water 4. Ultrasonic energy is emitted from a transducer 6 through the water 4 into the component 1. After passing through the component 1, the ultrasonic energy is directed off a reflector back through the component to the transducer 6. The received ultrasonic energy is processed by an ultrasonic measurement system (not shown) to build up a picture of the internal structure of the component.

A delamination defect 5 emanates from the hole 2. When the component 1 is placed in the tank 3, the water flows 4 into the hole 2 and fills the delamination defect 5. As a result the defect 5 becomes difficult to detect by the ultrasonic measurement system. For this reason, conventional ultrasonic immersion techniques can be unreliable for detecting such defects.

One conventional solution to this problem is to place the transducer in direct contact with the panel, thus removing the requirement of a liquid coupling medium. However this can be labour intensive and time consuming. Another conventional solution is to use a phased array ultrasound device, again in direct contact with the panel, thus removing the requirement of a liquid coupling medium. However, this can be expensive and requires a specially trained operator.

SUMMARY OF THE INVENTION

A first aspect of the preset invention provides a method of inspecting a component, the component comprising a hole with an entrance, the method comprising: directing ultrasound into the component via a liquid coupling medium; receiving ultrasound from the component via the liquid coupling medium; processing the received

ultrasound to determine a property of the component; and sealing the entrance of the hole with tape to prevent the liquid coupling medium from flowing into the entrance of the hole, wherein the tape has an acoustic impedance within 40% of the acoustic impedance of the liquid coupling medium.

A second aspect of the invention provides apparatus for inspecting a component, the component comprising a hole with an entrance, the apparatus comprising: an ultrasound measurement device; and a tape for sealing the entrance of the hole, the tape having an acoustic impedance within 40% of the acoustic impedance of water (that is, the tape has an acoustic impedance within 40% of 1.49×10^6 $kg \cdot s^{-1} \cdot m^{-2}$).

By selecting a tape with an acoustic impedance relatively close to that of the liquid coupling medium (which in most cases will be water) the tape is relatively transparent to ultrasound and thus enables at least the presence or absence of a defect in a wall of the hole to be determined.

Typically the tape has an acoustic impedance within 30% of the acoustic impedance of the liquid coupling medium. More preferably the tape has an acoustic impedance within 20% of the acoustic impedance of the liquid coupling medium.

Typically the tape has a longitudinal wave velocity within 40% of the longitudinal wave velocity of the liquid coupling medium, preferably within 30% and most preferably within 20%.

Typically the tape attenuates the ultrasound being directed into the component by less than 6dB, preferably by less than 4dB.

Typically the component is made of a laminate material such as a fibre-reinforced composite. The method can then be used to detect the presence or absence of delamination defects within the component, and particular delamination defects in a wall of the hole.

The hole may be a through-hole with two entrances, or a blind hole with only one entrance. In the case of a through-hole, both entrances are typically sealed with the tape.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention will now be described with reference to the accompanying drawings, in which:

Figure 1 shows a component with a hole in a conventional ultrasonic immersion testing configuration;

Figure 2 shows a component with a hole sealed with tape;

Figure 3 shows a method of inspecting the component of Figure 2; and

Figure 4 shows an alternative method of inspecting the component of Figure 2.

DETAILED DESCRIPTION OF EMBODIMENT(S)

Figure 2 shows a composite component 10 comprising a drilled hole 11 which passes vertically through the component 10, penetrating both its upper and lower surfaces 14, 15 to produce upper and lower entrances. The component 10 is made from a Carbon Fibre Reinforced Plastic (CFRP) composite material, with plies of the material terminating at the hole 11. A delamination defect 18 is shown emanating from the side of the hole 11.

Tape 19 is applied to seal both the upper and lower entrances of the hole 11. The tape 19 is attached to the upper and lower surfaces 14, 15 of the composite component 10 with a thin layer of water resistant adhesive (not shown). The adhesive used to attach the tape 19 to the component 10 cures at room temperature, which makes the tape 19 easy to apply. After the tape 19 has been applied, a scraper 16 is scraped across it as shown in Figure 2 to remove air bubbles. The scraper 16 is transparent to enable any air bubbles to be seen by an operator.

Next the component 10 is immersed in a water tank 12 as shown in Figure 3, the tape 19 preventing the water 13 from entering the hole 11 through either the upper or lower entrances.

Ultrasound energy 22 is emitted from an ultrasound transducer 20 and directed into the component 10 via the water 13. After passing through the component 10, the

energy is reflected by a glass reflector plate 21 back through the component 10 and the water 13 to the ultrasound transducer 20. The received ultrasound 23 is then processed by a measurement system 24 to determine a property of the component 10.

The transducer 20 transmits a short pulse of ultrasound energy and receives a series of reflected pulses caused by: a) reflection from the front face of the component; b) reflection from any defects within the component; c) reflection from the rear face of the component; and d) reflection from the plate 21. The system 24 may analyse these pulses in a number of ways. For instance the system 24 may measure the time of arrival of the pulse b) from a defect within the component. This gives information on the presence or absence of a defect, and its depth within the component. Alternatively the amplitude of the pulse d) may be measured. Since this pulse has passed twice through the component, its amplitude gives an indication of the total attenuation loss through the component and hence an indication of the presence or absence of defects. The transducer is scanned in a raster pattern parallel to the component to build up a two-dimensional image of the component. Typically the data is presented as a colour image where the colour of each pixel gives either the depth of a defect, or the attenuation loss through the component.

The water 13 in the tank 12 acts as a coupling medium through which the ultrasonic energy can flow with relatively low and uniform attenuation. As the tape 19 prevents the water 13 from flowing into the hole 11, the delamination defect 18 is filled with air. Air has a substantially greater acoustic impedance than both the water coupling medium and the composite material of the component 10. Thus, the ultrasound is attenuated more severely when it passes through the defect 18. This enables the defect 18 to be discriminated from its surroundings by the measurement system 24.

The combination of the adhesive layer and the tape 19 attenuates the ultrasound 22 being directed into the component by less than 6dB (and preferably by less than 4dB) in each direction. This allows a sufficient quantity of ultrasonic energy to be returned to the transducer 20 to enable inspection of the internal structure of the component within the taped region.

The tape 19 and the adhesive are made from materials which have acoustic impedances similar to that of water (which has an acoustic impedance of 1.49 x 10^6 rayl = 1.49 x 10^6 $kg \cdot s^{-1} \cdot m^{-2}$). This is beneficial as little or no extra work is required to take account of the tape 19 or the adhesive in the interpretation of the ultrasonic images generated by the measurement system.

For the tape, a material such as NUWC XP-1 polyurethane urea; PRC-Desoto's PR-1547 or PR-1592; or Cytech's Conathane EN-7 are suitable. These have acoustic impedances around 1.71 x 10^6 rayl - that is, approximately 15% higher than that of water. It is expected that this tape material will introduce an attenuation loss lower than 3dB in each direction.

The tape is manufactured by a simple extrusion process or by a calendaring process.

The adhesive is applied to the tape by spraying or dipping. For the adhesive, materials such as Epoxy Adhesive DP-190 are suitable. Because only a thin layer of adhesive is needed to bond the tape to the component, the acoustic impedance of the adhesive is not critical.

Preferably the tape 19 also has a similar longitudinal wave velocity to that of water (which is 1430m/s). This allows the measurement system to employ a time of flight algorithm (such as the pulse-echo technique) to process the received ultrasonic signals without the need to introduce additional measurement compensations.

NUWC XP-1 polyurethane urea, PRC-Desoto's PR-1547 and PR-1592 and Cytech's Conathane EN-7 have densities which are all comparable to that of pure water at room temperature (for example PR 1547 has a density of 1.05 g/cm^3 compared to water which is 1 g/cm^3). As acoustic impedance is calculated as (density X velocity) then it can be seen that these materials have longitudinal wave velocities that are comparable to that of water.

Although a double-pass through transmission ultrasound measurement system is shown in Figure 3, other measurement modes could be employed including a single-pass through transmission technique.

Moreover, the water path providing the coupling between the ultrasound transducer 20 and the component 10 may be provided by squirting a jet of water onto the component instead of fully immersing the component in water. An example is shown in Figure 4 in which a transmitter 30 directs ultrasound into the component via a water jet 31 spraying onto the component from above, and a receiver 32 receives ultrasound from the component via a water jet 33 spraying onto the component from below.

Although a water coupling medium is used in the examples described, any other suitable liquid coupling medium could be used. In this case the tape and adhesive are preferably chosen to have a similar acoustic impedance and longitudinal wave velocity to that of the alternative coupling medium.

Although the invention has been described above with reference to one or more preferred embodiments, it will be appreciated that various changes or modifications may be made without departing from the scope of the invention as defined in the appended claims.

Claims

1. A method of inspecting a component, the component comprising a hole with an entrance, the method comprising:

    a. directing ultrasound into the component via a liquid coupling medium;

    b. receiving ultrasound from the component via the liquid coupling medium;

    c. processing the received ultrasound to determine a property of the component; and

    d. sealing the entrance of the hole with tape to prevent the liquid coupling medium from flowing into the entrance of the hole, wherein the tape has an acoustic impedance within 40% of the acoustic impedance of the liquid coupling medium.

2. The method of any preceding claim wherein the tape has an acoustic impedance within 30% of the acoustic impedance of the liquid coupling medium.

3. The method of any preceding claim wherein the tape has an acoustic impedance within 20% of the acoustic impedance of the liquid coupling medium.

4. The method of any preceding claim wherein the tape has a longitudinal wave velocity within 40% of the longitudinal wave velocity of the liquid coupling medium.

5. The method of any preceding claim wherein the tape has a longitudinal wave velocity within 30% of the longitudinal wave velocity of the liquid coupling medium.

6. The method of any preceding claim wherein the tape has a longitudinal wave velocity within 20% of the longitudinal wave velocity of the liquid coupling medium.

7. The method of any preceding claim wherein the tape attenuates the ultrasound being directed into the component by less than 6dB.

8. The method of any preceding claim where the tape is adhered to the surface of the component with adhesive.

9. The method of claim 8 wherein the adhesive is an epoxy resin which cures at room temperature.

10. The method of any preceding claim wherein the component is made of a laminate material.

11. The method of any preceding claim wherein the received ultrasound is processed to determine the presence or absence of a defect in a wall of the hole.

12. Apparatus for inspecting a component, the component comprising a hole with an entrance, the apparatus comprising:

    a. an ultrasound measurement device; and

    b. a tape for sealing the entrance of the hole, the tape having an acoustic impedance within 40% of the acoustic impedance of water (1.49×10^6 $kg \cdot s^{-1} \cdot m^{-2)}$.

13. The apparatus of claim 12 wherein the tape has an acoustic impedance within 30% of the acoustic impedance of water (1.49×10^6 $kg \cdot s^{-1} \cdot m^{-2}$).

14. The apparatus of claim 13 wherein the tape has an acoustic impedance within 20% of the acoustic impedance of water (1.49×10^6 $kg \cdot s^{-1} \cdot m^{-2}$).

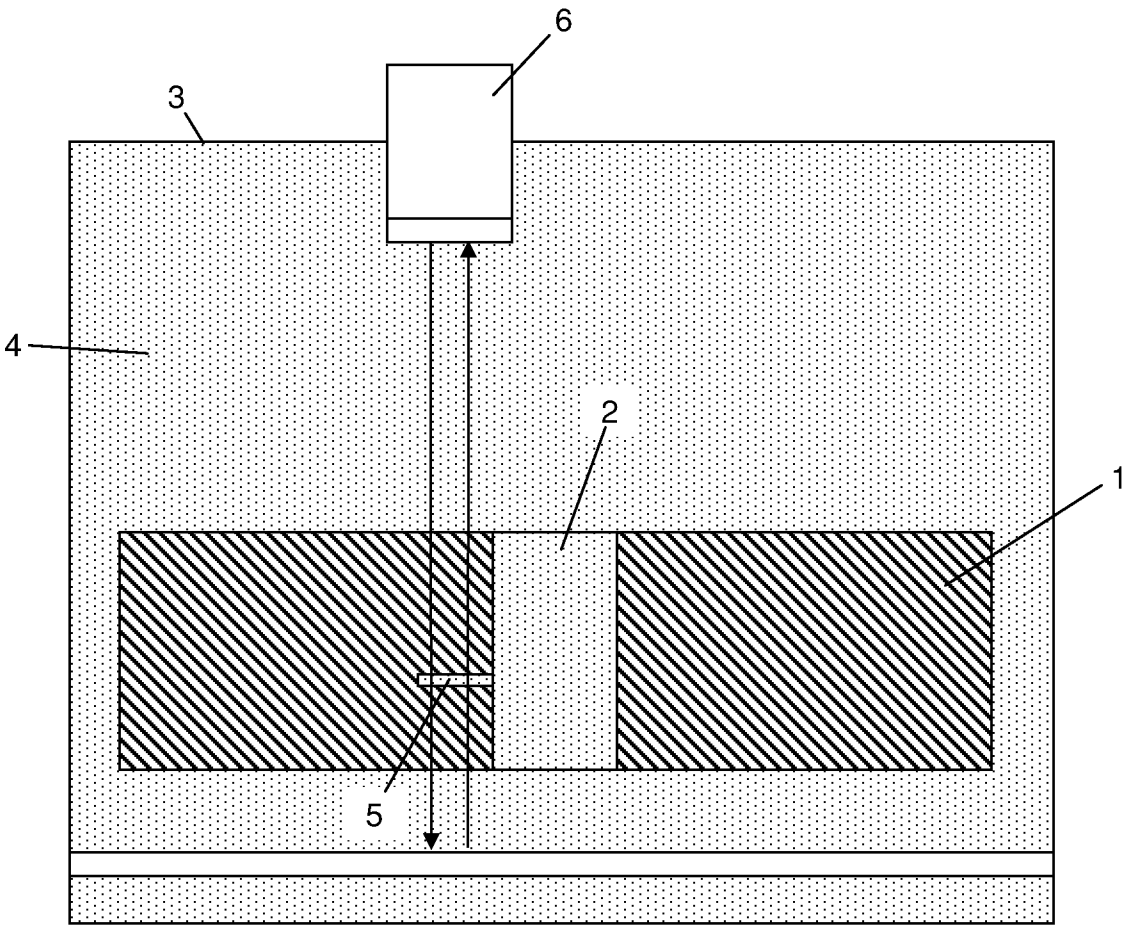


Figure 1

Figure 2

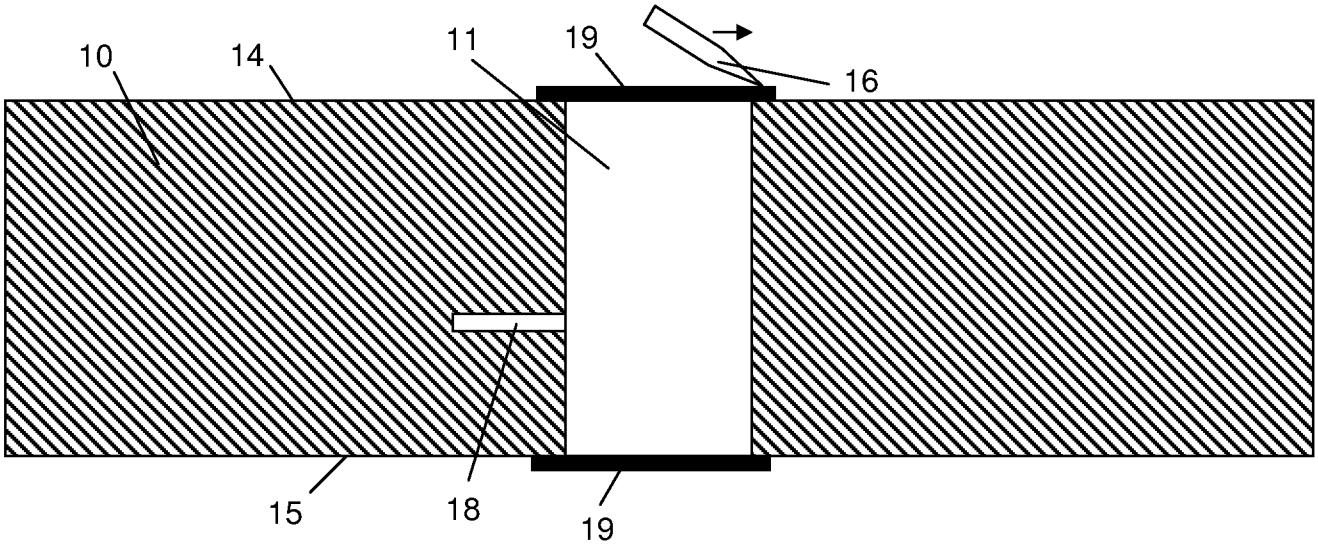
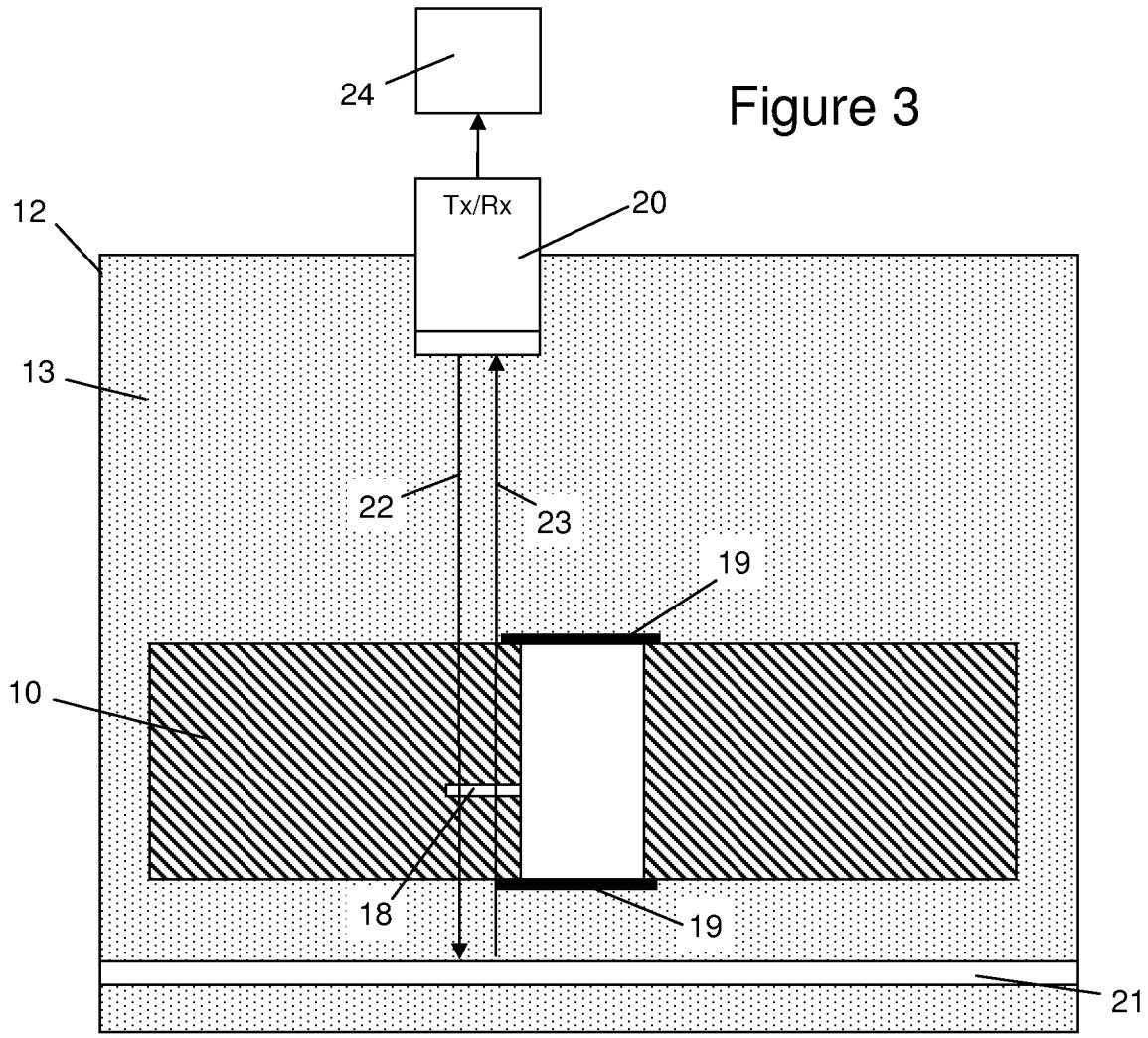


Figure 3



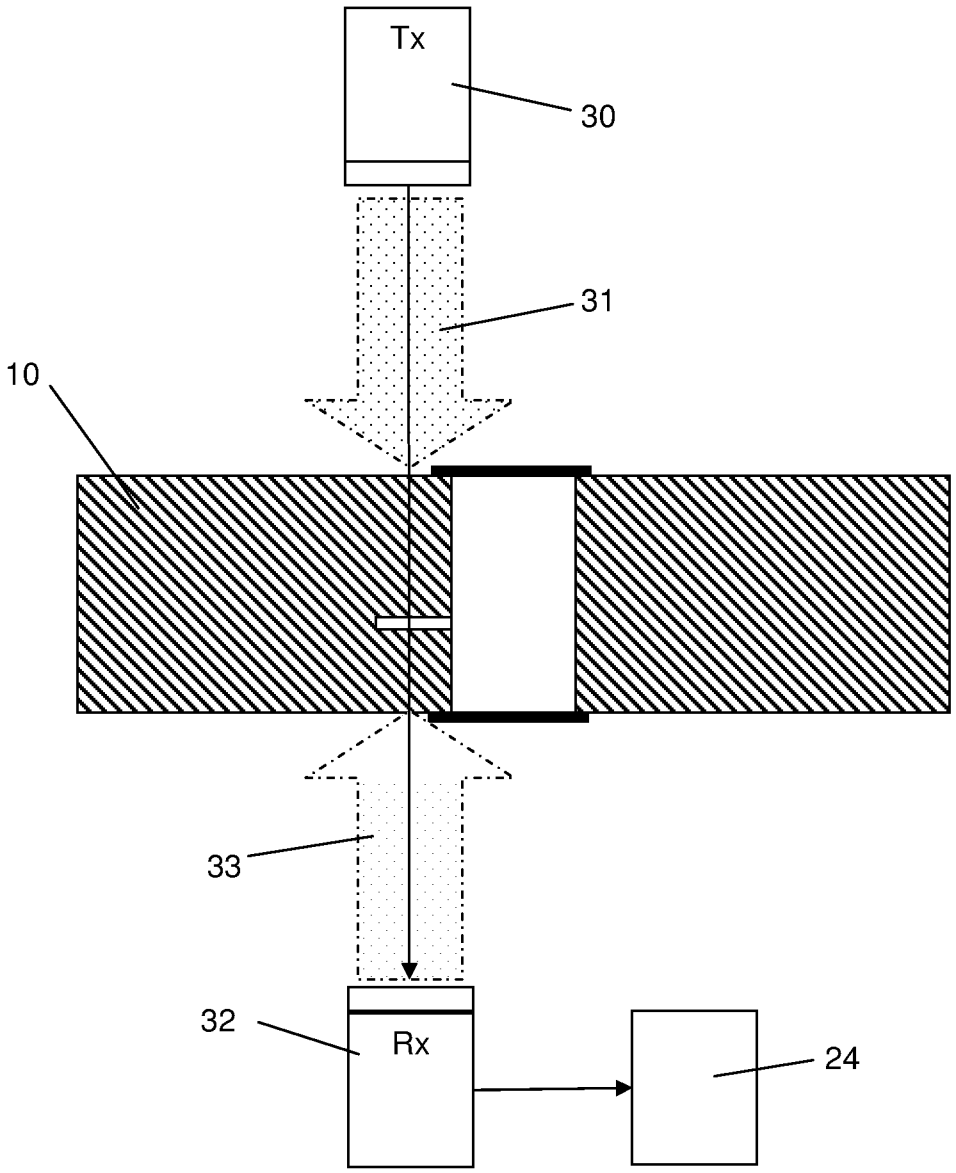


Figure 4

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2009/050390

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01N29/28 G10K11/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G01N G10K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal, WPI Data, INSPEC, COMPENDEX, IBM-TDB

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GB 2 292 610 A (BRITISH AEROSPACE [GB]) 28 February 1996 (1996-02-28) page 1, lines 3-6 page 4, lines 14,15 page 8, last paragraph - page 9, paragraph 1	1-6, 11-14
A	page 11, paragraph 2; claims 5,7	8-10
X	US 4 410 826 A (WAXMAN ALBERT S [US] ET AL) 18 October 1983 (1983-10-18)	12-14
A	abstract; figure 5 column 6, lines 54-64	1
X	US 2008/053230 A1 (KATSURA HIROAKI [JP] ET AL) 6 March 2008 (2008-03-06)	12
A	abstract; figure 1d paragraphs [0001], [0008], [0038]	1

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
16 July 2009	27/07/2009

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Filipas, Alin

1

INTERNATIONAL SEARCH REPORT

International application No.
PCT/GB2009/050390

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☒ Claims Nos.: 7
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
see FURTHER INFORMATION sheet PCT/ISA/210

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers allsearchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search reportcovers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

Continuation of Box II.2

Claims Nos.: 7

Claim 7 does not meet the requirements of Article 6 PCT in that the matter for which protection is sought is not defined - the claim only attempts to define the subject-matter in terms of the result to be achieved (attenuation less than 6 dB), instead of indicating how the desired effect is to be achieved.

The applicant's attention is drawn to the fact that claims relating to inventions in respect of which no international search report has been established need not be the subject of an international preliminary examination (Rule 66.1(e) PCT). The applicant is advised that the EPO policy when acting as an International Preliminary Examining Authority is normally not to carry out a preliminary examination on matter which has not been searched. This is the case irrespective of whether or not the claims are amended following receipt of the search report or during any Chapter II procedure. If the application proceeds into the regional phase before the EPO, the applicant is reminded that a search may be carried out during examination before the EPO (see EPO Guideline C-VI, 8.2), should the problems which led to the Article 17(2)PCT declaration be overcome.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/GB2009/050390

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
GB 2292610 A	28-02-1996	NONE	
US 4410826 A	18-10-1983	NONE	
US 2008053230 A1	06-03-2008	CN 101069095 A WO 2006075615 A1	07-11-2007 20-07-2006