



(51) International Patent Classification:
G01H 9/00 (2006.01)

(21) International Application Number:
PCT/IB2022/061087

(22) International Filing Date:
17 November 2022 (17.11.2022)

(25) Filing Language: English

(26) Publication Language: English

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TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

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

Declarations under Rule 4.17:

- as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))
- of inventorship (Rule 4.17(iv))

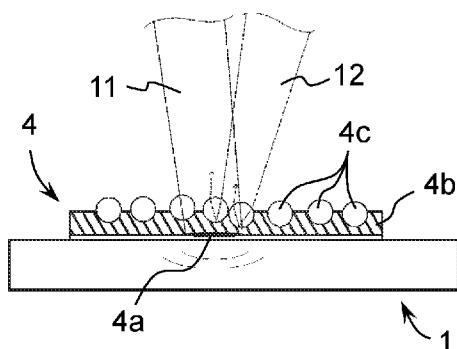
Published:

- with international search report (Art. 21(3))

(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, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CV, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IQ, IR, IS, IT, JM, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ,

(54) Title: LASER-BASED ULTRASOUND INSPECTION SYSTEM

FIG. 2



(57) Abstract: A laser-based ultrasound inspection system comprising an object for inspection (1), a laser device for ultrasound generation (3a), a laser device for ultrasound detection (3b), and a coating arrangement (4) including a laser absorbing layer (4a) disposed on a surface (2) of the object for inspection (1), a backing layer (4b) disposed over the laser absorbing layer (4a), and reflective particles (4c) or a partially reflective layer coupled to the surface (2) of the object for inspection.

LASER-BASED ULTRASOUND INSPECTION SYSTEM

Field of the invention

This invention relates to a laser-based ultrasound inspection system.

5

Background of the invention

Ultrasonic testing methods currently used in the industry typically necessitate physical contact to the specimen and/or a liquid couplant in order to achieve the acoustic impedance matching and improve the ultrasound transmission. They often need to be performed manually by a properly qualified operator
10 however despite strictly defined standards, the factor of the subjective interpretation by the operator cannot be avoided.

Ultrasonic immersion testing is a frequently used method with the disadvantage that the specimen and the ultrasonic probes need to be immersed in a liquid such as water. For many applications, immersion may
15 not be possible or practical, or may be too costly or complex to set up compared to other inspection techniques.

Air-coupled ultrasound avoids the drawbacks of ultrasonic immersion technology however can typically only be used on large plate-like objects in through-transmission setup. The objects of more complex
20 geometry face problems since it is not possible to distinguish between the low-intensity information-carrying ultrasound transmitted through the solid specimen and ultrasound transmitted directly through air, which disturbs the measurement. Air-coupled ultrasound transducers are narrowband and have low characteristic testing frequencies (typically between 50 kHz and 500 kHz), which causes a significant decrease in resolution and detection sensitivity.

25

Lasers are currently broadly used in the industry for inspection of external geometry and surface quality of manufactured parts. Although it is *per se* known to use lasers to generate ultrasound, or to read ultrasound vibrations on the surface of an object, there is no product in the market for industrial ultrasonic inspection of internal properties using lasers for both excitation and detection directed on the surface of a non-
30 immersed specimen to be inspected, due to the difficulty of obtaining a reliable measurement signal that has sufficient bandwidth and signal to noise ratio using only laser systems for both the excitation and the detection of ultrasound on various surface materials of objects for inspection.

Summary of the invention

An object of the invention is to provide a laser-based ultrasound inspection system that is economical to
35 implement and that allows reliable and accurate ultrasound inspection of internal properties of an object.

It is advantageous to provide a laser-based ultrasound inspection system that is versatile and can be easily implemented on objects of diverse geometries and sizes.

5 It is advantageous to provide a laser-based ultrasound inspection system that is easy to set up and operate and requires minimal manual intervention.

It is advantageous to provide a laser-based ultrasound inspection system that is rapid.

10 It is advantageous to provide a laser-based ultrasound inspection system that is compact.

It is advantageous to provide a laser-based ultrasound inspection system that is able to detect a large range of defects or anomalies in an inspected object.

15 Various objects of this invention have been achieved by providing the laser-based ultrasonic inspection system according to the independent claims. Dependent claims set forth advantageous embodiments of the invention.

20 Disclosed herein, is a laser-based ultrasound inspection system comprising an object for inspection, a laser device and a coating arrangement including a laser absorbing layer disposed on a surface of the object for inspection, a backing layer disposed over the laser absorbing layer, and reflective particles or a partially reflective layer coupled to the surface of the object for inspection.

25 In an advantageous embodiment, the partially reflective layer or reflective particles are in or on the backing layer and/or the laser absorbing layer.

In an advantageous embodiment, the partially reflective layer or reflective particles are disposed in or on a second backing layer positioned on the surface of the object for inspection separately from the laser absorbing layer covered by the first backing layer.

30 In an advantageous embodiment, the reflective particles are retro-reflective particles.

In an advantageous embodiment, the retro-reflective particles are ball-shaped, for instance substantially spherical.

35 In an advantageous embodiment, the reflective particles have a refractive index that is greater than a refractive index of the backing layer.

In an advantageous embodiment, the partially reflective layer is configured to split a laser beam for ultrasound generation and laser for ultrasound detection into a beam passing through the backing layer on to the absorbing layer, and a reflected beam for reading of ultrasound waves.

- 5 In an advantageous embodiment, a material of the laser absorbing layer is selected from anyone or more of hydrogenated (or black) hydrogenated titanium dioxide, carbon nanotubes, graphite powder mixed with epoxy resin, gold nanopores, black carbon with polydimethylsiloxane, reduced graphene oxide, polydimethylsiloxane, metals (e.g. aluminum, chromium, copper) and polymers (e.g. high density polyethylene, polycarbonate, acrylonitrile butadiene styrene).

- 10 In an advantageous embodiment, a material of the backing layer is selected from anyone or more of silica (silicon dioxide), borosilicate, fluoride, aluminate, borate, phosphate, chalcogenide, sapphire, or similar glasses (crown and flint) and glass ceramics, polyethylene, polyvinyl chloride, terephthalate, polystyrene, polypropylene, polycarbonate, polymethyl methacrylate or similar, wherein the materials may include one
15 or more of the following additives thorium oxide, lanthanum oxide, lead oxide, cerium oxide, calcium oxide, magnesium oxide, aluminium oxide, boric oxide, sodium carbonate, germanates, nitrates, carbonates, plastics, acrylic, titanates, arsenates, antimonates, tellurites, metals, aluminates, phosphates, chalcogenides, borates, fluorides.

- 20 In an advantageous embodiment, a material of the reflective layer or particles is selected from anyone or more of silica (silicon dioxide), borosilicate, fluoride, aluminate, borate, phosphate, chalcogenide, sapphire, or similar glasses (crown and flint) and glass ceramics, polyethylene, polyvinyl chloride, terephthalate, polystyrene, polypropylene, polycarbonate, polymethyl methacrylate, wherein the materials may include one or more of the following additives thorium oxide, lanthanum oxide, lead oxide, cerium oxide, calcium
25 oxide, magnesium oxide, aluminium oxide, boric oxide, sodium carbonate, germanates, nitrates, carbonates, plastics, acrylic, titanates, arsenates, antimonates, tellurites, metals, aluminates, phosphates, chalcogenides, borates, fluorides.

- 30 In an advantageous embodiment, the coating arrangement has a thickness in a range of 0.1 mm to 2 mm, a thickness of the laser absorbing layer being in a range of 10 μ m to 0.5 mm, and the backing layer having a thickness in a range of 0.5 mm to 2 mm.

- In an advantageous embodiment, the laser device comprises a laser ultrasound generator and a laser ultrasound detector in a single unit.

- 35 In an advantageous embodiment, the laser device comprises a laser ultrasound generator and a separate laser ultrasound detector.

In an advantageous embodiment, the system further comprises a measurement computing system having program modules installed and executable therein, the program module including a machine learning algorithm, and databases including at least a test objects reference database used by the machine learning
5 algorithm.

In an advantageous embodiment, the system further includes at least one training object comprising at least one active element of the training object configured to alter the ultrasound propagation characteristics of the test object according to a state of the active element, the test object used for training the machine learning
10 algorithm of the measurement computing system.

Further objects and advantageous aspects of the invention will be apparent from the claims, and from the following detailed description and accompanying figures.

15 **Brief description of the drawings**

Figure 1 is a schematic block diagram illustrating an overview of a laser based ultrasound inspection system according to an embodiment of the invention;

20 **Figure 2** is a schematic view in cross-section of an object under inspection with a coating according to a first embodiment of the invention;

Figure 3a is a view similar to figure 2 of another embodiment in which the laser ultrasound generation is in a location separate from the laser ultrasound reading of the inspected object;

25 **Figure 3b** illustrates a variant of figure 3a in which the laser ultrasound generation and laser ultrasound reading are performed on opposite sides of the inspected object;

Figure 4 is a schematic representation of a laser device for laser ultrasound generation and reading
30 according to an embodiment of the invention;

Figure 5 is a view similar to figure 4 in which the laser ultrasound generator is separate from the laser ultrasound detector;

35 **Figure 6a** is a schematic cross-sectional representation of a training object for inspection for training a machine learning process of a measurement computing system according to an embodiment of the invention;

Figures 6b and 6c are views similar to 6a of variants of test objects;

Detailed description of embodiments of the invention

Referring to the figures, starting with figure 1, a laser-based ultrasound inspection system comprises a laser device 3, a measurement computing system 5, and an object for inspection 1 comprising a coating arrangement 4 on an outer surface of the object for inspection. The computing system 5 is connected to the laser device 3 at least during the time required to upload ultrasound measurements results generated by the laser device. The computing system may however comprise a laser control module and be connected to the laser during an inspection process in order to control a scanning process of the laser on the surface of the inspected object and receive the measurement results fed back from the laser during the scanning process.

The computing system comprises a machine learning program module for interpreting the measurement results from the laser device and that may include a training phase using test objects 1b that have known properties.

Within the scope of the invention, the test objects may be actively controlled and have varying properties that allow improved training of the machine learning program module. The computing system may have a reference database stored therein and that may be updated with measurement results based on training data and on measurement data of the inspected objects over time.

Laser pulses allow effective broadband and contact-free generation of ultrasound in solids. Broadband laser ultrasound delivers additional and more precise information about the quality inspection properties than conventional air or liquid coupled ultrasound techniques, and benefit from the advantages of contact-free methods that are faster, more robust, and are easier to be automated than contact-based methods. With laser technology it is possible to generate very short pulses (ns, ps, fs) of high peak power (e.g. hundreds MW) and it is possible to generate ultrasound without physical contact directly with the object for inspection. Two solid-to-air interfaces are thus omitted (transmitter-to-air and air-to-specimen), in comparison to a more traditional solution of air-coupled transducers, for which typically only around 0.1% of the ultrasound energy is transmitted at each such interface.

For laser-based ultrasonic excitation in the thermoelastic regime, ultrasound is generated due to the fast thermal expansion and contraction of a thin material layer on the specimen surface. For higher pulse energies, small explosions on the specimen surface and ablated particles generate ultrasound (ablative regime).

Efficiency of ultrasound generation by laser pulses may be improved, for instance by a factor of up to 100, by introducing a backing-mass layer. The backing layer may comprise a solid or liquid (partly) transparent

layer applied on the surface of the object for inspection and which preferably has mechanical properties (acoustic impedance) similar to the object for inspection. In contrast to air backing (when no backing-mass layer is present), ultrasound is generated at the transition between this transparent layer and an opaque object for inspection; and not at the transition between the air and the object for inspection. As a consequence, a higher share of laser pulse energy will be converted to the ultrasound energy propagating in the object for inspection and less of the energy will be lost to the surrounding media e.g. by created plasma, kinetic energy of ablated particles, or air-propagating ultrasound. In this case, the ultrasound is generated in the bulk of the object for inspection by an effect similar to a subsurface explosion.

An absorptive layer with high coefficient of thermal expansion is applied between the object for inspection and the transparent backing-mass layer. Efficiency of ultrasound detection by a laser beam probe (laser-Doppler vibrometers, interferometers) is conditioned by the amount of light captured by the measuring device. A high power of the laser beam reflected back to the receiving optics of the laser reader is advantageous. In many cases, light scattered in all directions on the rough object for inspection surface does not suffice.

Referring now to figures 2, 3a and 3b, coating arrangements according to embodiments of the invention are illustrated.

In a first variant, the coating arrangement 4 includes a single coating for both laser ultrasound generation and laser ultrasound reading. In this configuration, the laser device for ultrasound generation 3a generates a laser beam 11 that is absorbed and generates ultrasound in thermoelastic or ablative regime. A laser beam for ultrasound detection 12 is generated and captured by the laser device for ultrasound detection 3b.

The laser source beam 11 is configured to generate ultrasound in the object for inspection 1 and the laser for ultrasound detection 12 transmits vibration of the surface 2 of the object for inspection 1 to the laser device 3. The reflected signal represents the object's response to ultrasound stimulation that is dependent on the internal properties of the object and that allows to distinguish objects with defects or other anomalies from objects without defects or anomalies.

The coating arrangement 4 according to a first embodiment illustrated in figure 2 comprises a laser absorbing layer 4a positioned on the surface 2 of the object for inspection 1, a backing layer 4b mounted over the laser absorbing layer 4a. The backing layer is transparent or at least partially transparent to the laser source beam 11 to allow the laser source beam 11 to at least partially reach and interact with the laser absorbing layer 4a. Interaction of the laser source beam with the laser absorbing layer generates ultrasound due to the laser energy absorbed in the laser absorbing layer 4a.

The coating arrangement 4 further includes a reflective layer or reflective particles 4c configured to reflect part of the laser source beam back to the laser device. The reflective particles 4c may advantageously be embedded in a backing layer 4b, which may also serve as the backing layer positioned over the laser absorbing layer, or a backing layer positioned directly on the surface of the object for inspection, depending on the embodiment. The reflective particles 4c may also be provided in a reflective particle support layer material that is different from the material of the backing layer 4b.

Since the reflective layer or reflective particles are coupled to the surface 2 of the object for inspection (e.g. via the backing layer), vibrations of the surface 2 due to ultrasound waves within the material of the object for inspection are captured in the laser beam for ultrasound detection 12.

In embodiments as illustrated in figures 3a and 3b, the coating arrangement 4 may comprise a laser absorbing layer 4a positioned against the surface 2 of the object for inspection and a backing layer 4b mounted over the absorbing layer similar to the previously described backing layer, and a separate reflective layer arrangement positioned on the surface 2 of the object for inspection in a separate position from the absorbing and backing layer arrangement 4a, 4b. In this variant, the laser source beam 11 is generated by a laser ultrasound generator 3a that is separate from a laser ultrasound detector 3b that generates a separate laser beam and receives in return a laser beam for ultrasound detection 12 for reading the vibrations of the surface 2 of the object for inspection at a separate position from the position where the ultrasound is generated. The functions of ultrasound generation and ultrasound reading on the surface of the object for inspection are thus separated into different zones. These zones may be positioned adjacently or in relative proximity on a same side of a surface of the object for inspection as illustrated in figure 3a, or on opposite sides of the object for inspection, as illustrated for instance in figure 3b. Various other positional arrangements such as top or bottom, and lateral sides may for instance be configured and the object for inspection although shown as a substantially planar with a constant thickness may have various 3-dimensional shapes.

In a preferred embodiment, the reflective particles 4c comprises retro-reflective particles, for instance in the form of balls, for instance substantially spherical balls of transparent material with a refractive index that is different to the refractive index of the backing layer 4b and that causes the light beam entering into the reflective particles to be internally reflected until the internal reflected light exits the particle on a side where the light enters the particle. The retroreflective properties can also be achieved by particles of other shapes such as tetrahedrons, or by various shaped particles with a reflective coating on the surface thereof.

In a variant, the reflective layer may have a partially reflective coating that splits the source laser beam into a transmission beam that traverses the reflective layer to impinge upon the absorbing layer, and a reflected

beam used to measure the ultrasound vibration of the coating coupled to the surface of the object for inspection.

Advantageously, the combination of the laser absorbing layer with a backing layer to improve the transmission of ultrasound energy captured in the absorbing layer to the object, and the use of a reflective layer or reflective particles to increase the amplitude of the reflected signal from the surface of the object for inspection significantly improves the signal to noise ratio and also allows for a broadband ultrasound generation and capture for accurate and reliable inspection of material properties within the object for inspection.

The material of the absorbing layer 4a is configured to increase laser light absorption and to generate ultrasound by its expansion and contraction in a thermoelastic regime. The material of the absorptive layer is thus selected to have a high light absorption level at the wavelength of the laser for ultrasound excitation and at the same time a high thermal expansion coefficient, while also providing sufficient bonding properties between the object for inspection and the backing layer.

According to embodiments of the invention, materials of the absorbing layer include hydrogenated (or black) hydrogenated titanium dioxide, carbon nanotubes, graphite powder mixed with epoxy resin, gold nanopores, black carbon with polydimethylsiloxane, reduced graphene oxide, polydimethylsiloxane, metals (e.g. aluminum, chromium, copper) and polymers (e.g. high density polyethylene, polycarbonate, acrylonitrile butadiene styrene). The absorbing layer may consist of or comprise a solid form, or may consist of or comprise a liquid or gel form.

According to embodiments of the invention, the materials of the backing layer 4b may advantageously include

- transparent and semi-transparent materials such as silica (silicon dioxide), borosilicate, fluoride, aluminate, borate, phosphate, chalcogenide, sapphire, or similar glasses (crown and flint) and glass ceramics;
- transparent or semi-transparent polymers such as polyethylene, polyvinyl chloride, terephthalate, polystyrene, polypropylene, polycarbonate, polymethyl methacrylate or similar;
- the backing layer materials may include additives such as thorium oxide, lanthanum oxide, lead oxide, cerium oxide, calcium oxide, magnesium oxide, aluminium oxide, boric oxide, sodium carbonate, germanates, nitrates, carbonates, plastics, acrylic, titanates, arsenates, antimonates, tellurites, metals, aluminates, phosphates, chalcogenides, borates, fluorides, or similar. The backing layer may consist of or comprise a solid form, or may consist of or comprise a liquid or gel form.

According to embodiments of the invention, the acoustic impedance of the material of the backing layer, and optionally also of the absorbing layer, is preferably similar to the material of the object for inspection as possible, typically in the range from $1.5 \times 10^6 \text{ kg m}^{-2} \text{ s}^{-1}$ and $50 \times 10^6 \text{ kg m}^{-2} \text{ s}^{-1}$. The backing layer material may thus be selected according to its acoustic impedance in order preferably to match or substantially match the acoustic impedance of the object for inspection to improve the transmission of ultrasound energy generated in the laser absorbing layer into the material of the object for inspection.

An example of a method of generating the coating comprises the steps of:

1. Fabrication of spherical retroreflectors,
2. Covering the surface of spherical retroreflectors with the layer of low refractive index in order to achieve sufficient internal reflections,
3. Applying the absorptive layer with high coefficient of thermal expansion on the specimen surface
4. Applying the backing-mass layer in the liquid state, which is transparent for the wavelength of excitation laser,
5. Applying the spherical retroreflectors,

Cohesive bonds between the layers must be strong enough to prevent delamination at the corresponding laser pulse energy.

Referring to figures 6a to 6c, for the purposes of improving the measurement of defects and anomalies in objects to be tested, various objects with various properties may be used for training the machine learning algorithms. These test objects may advantageously include objects with active elements 8 that alter the properties of a test object in a controlled manner. For instance, the active elements may include heating elements, magnetic elements, capacitive elements, piezoelectric elements, and any other form of active element that generates heat, magnetic field, electrical field, or a mechanical stress on the test object in which these active elements are integrated or mounted on, in order to vary the material properties of the test object. These allow, for instance to simulate certain material changes in a controlled predictable manner such that the ultrasound inspection of the test object may be used for training the machine learning algorithm. It may be noted that the computing system may also be fed measurement results from objects for inspection that are reference objects without anomalies or defects as a reference for subsequent testing of objects.

The laser-based ultrasound inspection system according to embodiments of the invention may advantageously be used for inspection of a large variety of objects such as: aircraft components, turbine blades, high-pressure vessels, pipelines, support structures, and other high-load or high-velocity components. The inspection system is applicable on a broad spectrum of materials – the most typical are metals, ceramics, concrete, polymers and various composites e.g. carbon-fiber-reinforced polymers. Typical production processes that require particular quality surveillance are welding, adhesive, soldering

and other similar joints, additive manufacturing and casting parts. The inspection system is useful for continuous quality surveillance of rolled metal sheets and profiles.

5 The coating arrangement 4 may be typically in a thickness range of 0.1 mm to 5 mm and therefore in many applications the inspected objects may be left with the coating, or in certain applications the coating may be removed from the inspected object by various processes such as subtractive machining, laser ablation, chemical etching, thermal combustion, and any other processes that may remove the coating from the object if needed.

10 According to an aspect of the invention, the interpretation of ultrasound signal measurement results may be assisted by a machine learning programs, in particular using neural networks in order to reduce the training data required when setting up the inspection system for a new object to be inspected.

15

List of feature references:

- Object for inspection 1
 - Surface 2
- 5 Laser device 3
 - Laser ultrasound generator 3a
 - Laser ultrasound reader / detector 3b
- Coating arrangement 4
 - Laser absorbing layer 4a
- 10 Backing layer 4b
 - Laser transparent layer
 - Reflective particles 4c
 - Retroreflective particles
- Measurement computing system 5
 - 15 Program modules 6
 - Machine learning
 - Databases 7
 - Test objects reference database
- Training object 8
 - 20 Electrodes or heating elements(s) 8a
 - Thermally-sensitive or piezoelectric, piezoelectric (or similar) material(s)
 - Laser beam for ultrasound generation 11 (laser source beam)
 - Laser beam for ultrasound detection 12 (laser detection beam)
 - Laser reflection beam
- 25 Galvanometer-driven scanning mirror 13
 - Optical or opto-mechanical unit to focus the laser beams 14
 - Optical unit to combine the paths of the laser beams 15

Claims

1. A laser-based ultrasound inspection system comprising an object for inspection (1), a laser device (3) and a coating arrangement (4) including a laser absorbing layer (4a) disposed on a surface (2) of the object for inspection (1), a backing layer (4b) disposed over the laser absorbing layer (4a), and reflective particles (4c) or a partially reflective layer coupled to the surface (2) of the object for inspection.
2. System according to the preceding claim wherein the partially reflective layer or reflective particles are in or on the backing layer (4b) and/or the laser absorbing layer (4a).
3. System according to the claim 1 wherein the partially reflective layer or reflective particles are disposed in or on a second backing layer positioned on the surface (2) of the object for inspection separately from the laser absorbing layer covered by the first backing layer.
4. System according to any preceding claim wherein the reflective particles are retro-reflective particles.
5. System according to the preceding claim wherein the retro-reflective particles are ball-shaped, for instance substantially spherical.
6. System according to any preceding claim wherein the reflective particles have a refractive index that is greater than a refractive index of the backing layer.
7. System according to any preceding claim wherein the partially reflective layer is configured to split a laser beam for ultrasound generation (11) and laser for ultrasound detection (12) into a beam passing through the backing layer on to the absorbing layer, and a reflected beam for reading of ultrasound waves.
8. System according to any preceding claim wherein a material of the laser absorbing layer is selected from anyone or more of hydrogenated (or black) hydrogenated titanium dioxide, carbon nanotubes, graphite powder mixed with epoxy resin, gold nanopores, black carbon with polydimethylsiloxane, reduced graphene oxide, polydimethylsiloxane, metals (e.g. aluminum, chromium, copper) and polymers (e.g. high density polyethylene, polycarbonate, acrylonitrile butadiene styrene).
9. System according to any preceding claim wherein a material of the backing layer is selected from anyone or more of silica (silicon dioxide), borosilicate, fluoride, aluminate, borate, phosphate, chalcogenide, sapphire, or similar glasses (crown and flint) and glass ceramics, polyethylene, polyvinyl chloride, terephthalate, polystyrene, polypropylene, polycarbonate, polymethyl methacrylate or similar, wherein the materials may include one or more of the following additives thorium oxide, lanthanum oxide, lead oxide, cerium oxide, calcium oxide, magnesium oxide, aluminium oxide, boric oxide, sodium

carbonate, germinates, nitrates, carbonates, plastics, acrylic, titanates, arsenates, antimonates, tellurites, metals, aluminates, phosphates, chalcogenides, borates, fluorides.

10. System according to any preceding claim wherein a material of the reflective layer or particles is
5 selected from anyone or more of silica (silicon dioxide), borosilicate, fluoride, aluminate, borate, phosphate, chalcogenide, sapphire, or similar glasses (crown and flint) and glass ceramics, polyethylene, polyvinyl chloride, terephthalate, polystyrene, polypropylene, polycarbonate, polymethyl methacrylate, wherein the materials may include one or more of the following additives thorium oxide, lanthanum oxide, lead oxide, cerium oxide, calcium oxide, magnesium oxide, aluminium oxide, boric oxide, sodium carbonate,
10 germinates, nitrates, carbonates, plastics, acrylic, titanates, arsenates, antimonates, tellurites, metals, aluminates, phosphates, chalcogenides, borates, fluorides.

11. System according to any preceding claim wherein the coating arrangement has a thickness in a range of 0.1 mm to 2 mm, a thickness of the laser absorbing layer being in a range of 10 μm to 0.5 mm,
15 and the backing layer having a thickness in a range of 0.5 mm to 2 mm.

12. System according to any preceding claim wherein the laser device comprises a laser ultrasound generator (3a) and a laser ultrasound detector (3b) in a single unit.

20 13. System according to any preceding claim 1-11 wherein the laser device comprises a laser ultrasound generator (3a) and a separate laser ultrasound detector (3b).

14. System according to any preceding claim further comprising a measurement computing system (5) having program modules (6) installed and executable therein, the program module (6) including a machine
25 learning algorithm, and databases (7) including at least a test objects reference database used by the machine learning algorithm.

15. System according to the preceding claim further including at least one training object comprising at least one active element of the training object (8) configured to alter the ultrasound propagation characteristics of the test object according to a state of the active element, the test object used for training
30 the machine learning algorithm of the measurement computing system.

FIG. 1

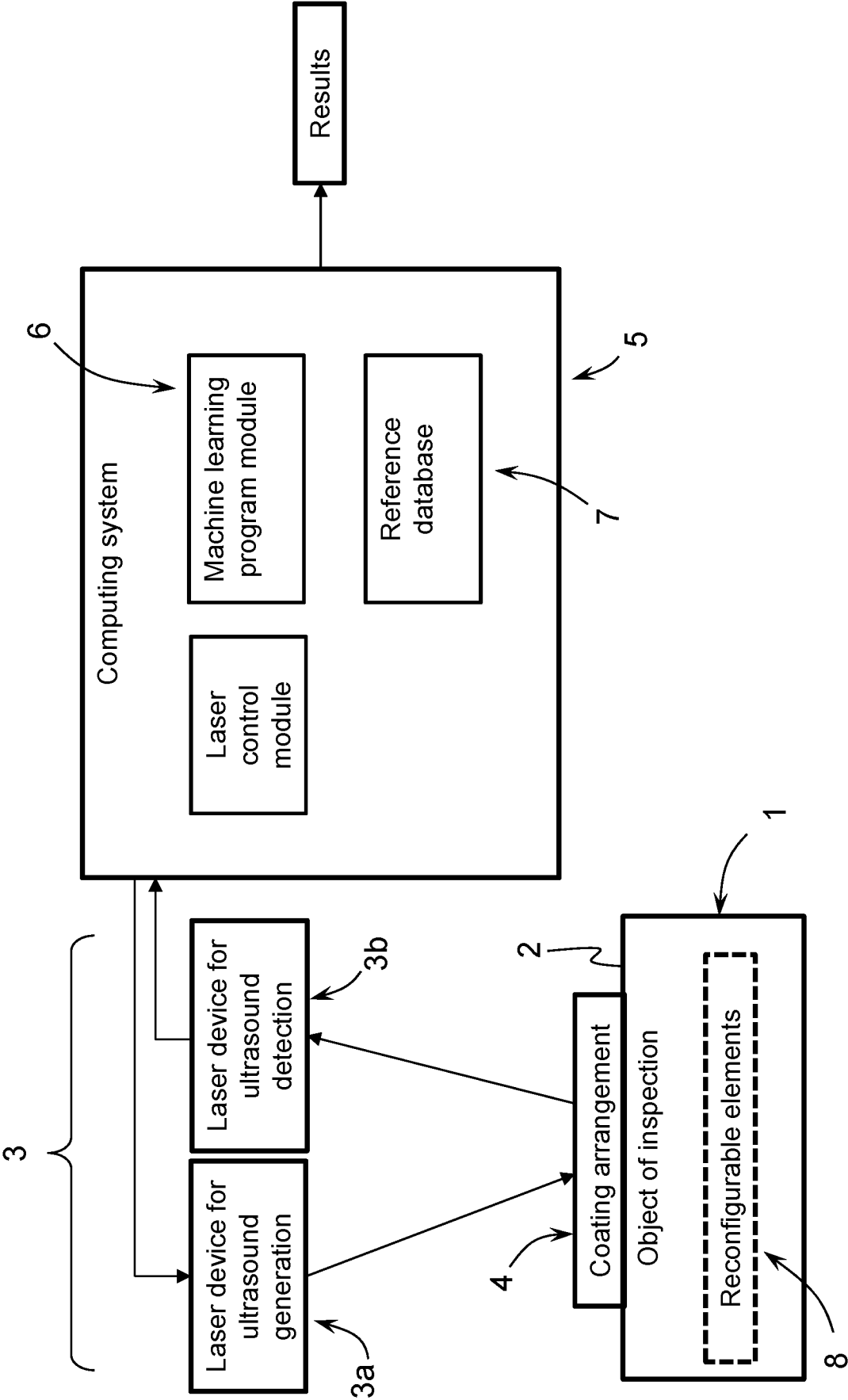


FIG. 2

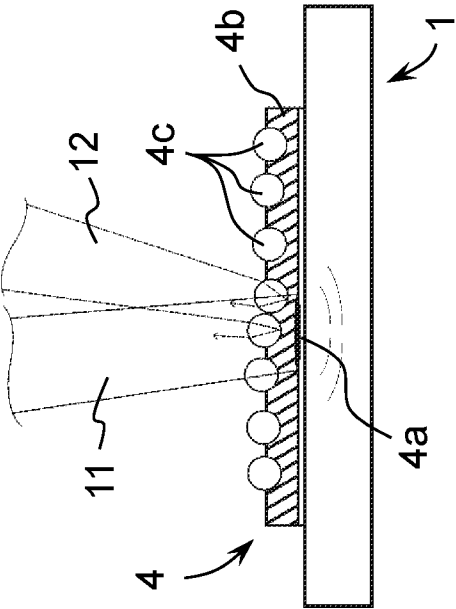


FIG. 3a

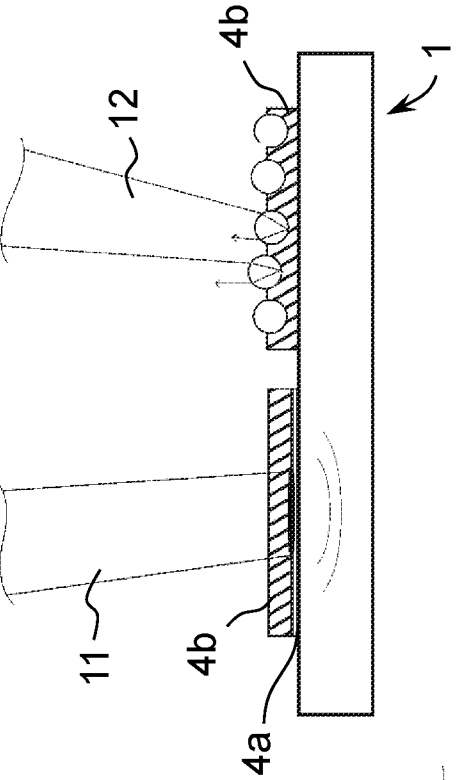


FIG. 3b

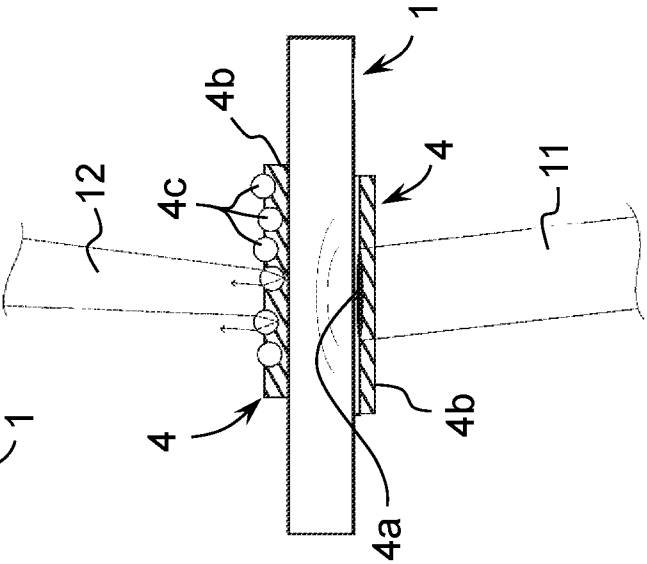


FIG. 4

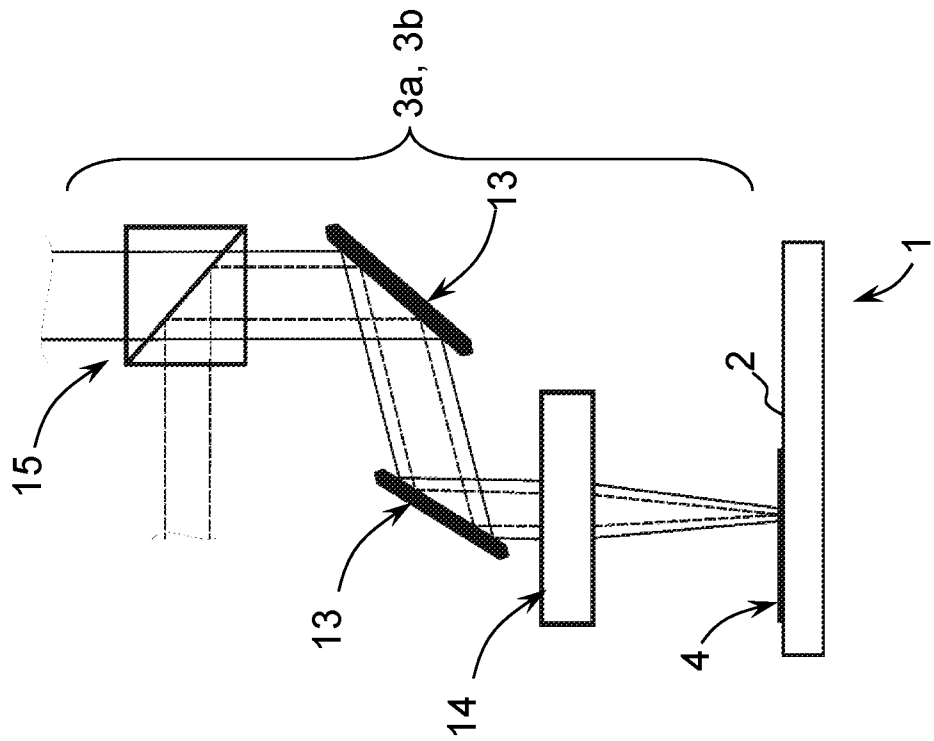


FIG. 5

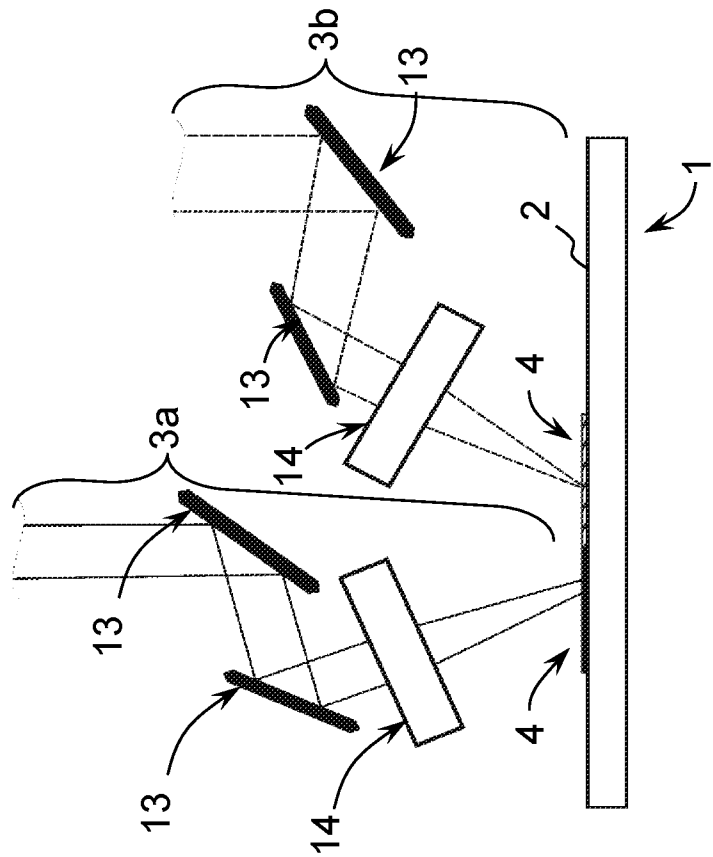


FIG. 6a

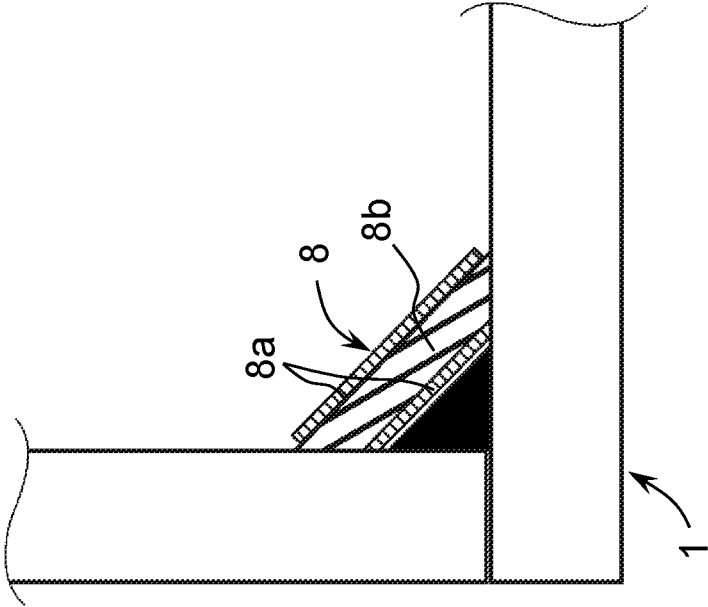


FIG. 6b

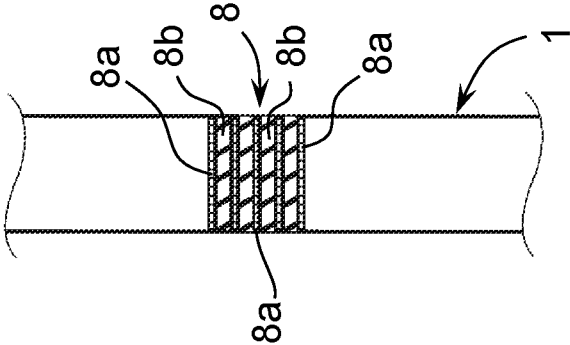
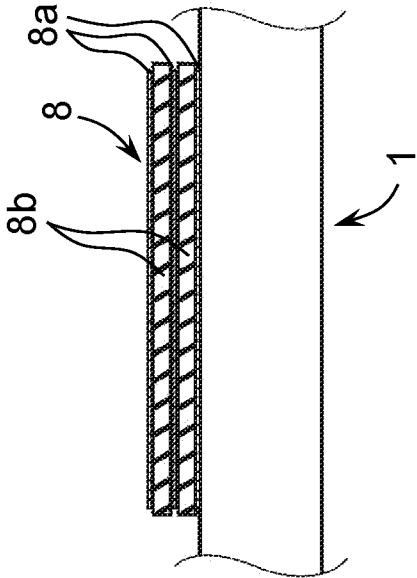


FIG. 6c



INTERNATIONAL SEARCH REPORT

International application No

PCT/IB2022/061087

A. CLASSIFICATION OF SUBJECT MATTER**INV. G01H9/00****ADD.**

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)

G01H G01N

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 practicable, 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	US 7 775 122 B1 (TOLLER STEVEN M [US] ET AL) 17 August 2010 (2010-08-17)	1-11, 14, 15
Y	column 3, lines 55-66; figures 1-5	12, 13
	column 5, lines 4-16	
	column 6, lines 15-16, 54-50	
	column 7, lines 6-8	
	column 8, lines 4-11; claims 18, 22	

Y	US 3 978 713 A (PENNEY CARL M) 7 September 1976 (1976-09-07)	12, 13
A	abstract; claims 4, 8; figure 1	1
	column 2, lines 30-36	
	column 2, line 64 - column 3, line 4	



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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Date of the actual completion of the international search

26 May 2023

Date of mailing of the international search report

05/06/2023

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/IB2022/061087

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
US 7775122	B1	17-08-2010	NONE	

US 3978713	A	07-09-1976	NONE	
