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Multiple channel laser ultrasonic system

Abstract

The present disclosure provides for a multiple channel laser ultrasonic system using a single detection laser and a single generation laser for inspecting internal structures. An example system includes a laser generator configured to emit generation laser light, a laser detector configured to emit detection laser light, and a scanning apparatus. The scanning apparatus is configured to receive the generation laser light and the detection laser light, direct the generation laser light and the detection laser light onto a surface of a structure via a plurality of laser ultrasonic channels, and collect reflections of the detection laser light from the surface of the structure via the plurality of laser ultrasonic channels. The system also includes a controller configured to characterize an internal feature of the structure based on the reflections.

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Background/Summary

FIELD

(1) The present disclosure relates to a laser ultrasound inspection system. More particularly, the present disclosure relates to a multiple channel laser ultrasonic system using a single detection laser and a single generation laser for inspecting internal structures of a component.

BACKGROUND

(2) In manufacturing aircraft, vehicles, and other structures, inspection of parts used to form these structures is often performed to determine whether the parts have appropriate parameters and properties for desired functions and performance. Additionally, the structures and/or parts may be inspected as part of normal maintenance. Nondestructive inspection is commonly used to evaluate the properties of a part without altering the ability of the part to be used for its desired function. Examples of nondestructive inspection include ultrasound testing, eddy current testing, x-ray testing, and visual inspections.

(3) Ultrasound testing is often used to perform inspections on aircraft parts that are formed of composite materials. Ultrasound testing involves transmitting acoustic waves (e.g., sound waves) through a test object and detecting a response to the acoustic waves. The response is analyzed to determine whether inconsistencies or defects are present in the test object.

(4) Ultrasound testing is commonly performed using a transducer that is configured to send acoustic waves into the test object and detect the response to the acoustic waves. Typically, the transducer is coupled to a surface of the test object by placing the transducer in physical contact with the test object. In many cases, a coupling medium, such as water, oil, a water-based gel, or some other liquid, is used to reduce the acoustic impedance between the transducer and the test object. However, in many cases, coupling the transducer to the surface of the test object may be difficult and complex. For example, when the test object has a non-constant geometry, a non-planar surface, or other non-planar features, it may be difficult and complex to couple the transducer to the test object in a manner that ensures that sound enters the test object in a desired direction, such as perpendicular to the surface.

(5) Laser ultrasound testing is an example of non-destructive inspection that allows for inspection of the test object without requiring physical contact with the test object. Typically, laser ultrasound testing uses a laser beam to generate ultrasonic waves in the test object and another separate laser beam to detect a response to the ultrasonic waves to generate data about the test object.

(6) Compared to ultrasonic testing systems, laser ultrasound testing systems are generally less sensitive to the orientation relative to the test object. However, it can take a significant amount of time to perform testing of composite materials used in certain structures, such as aircraft, with laser ultrasound testing systems. For example, the laser in laser ultrasound testing systems generally limit the rate of data acquisition, which tends to make such systems too expensive, slow, and bulky to be suitable for manufacturing inspection systems.

SUMMARY

(7) One embodiment of the present disclosure is a system. The system includes a laser generator, a laser detector, a scanning apparatus, and a controller. The laser generator is configured to emit generation laser light. The laser detector is configured to emit detection laser light. The scanning apparatus is configured to: receive the generation laser light and the detection laser light; direct the generation laser light and the detection laser light onto a surface of a structure via a plurality of laser ultrasonic channels; and collect reflections of the detection laser light from the surface of the structure via the plurality of laser ultrasonic channels. The controller is coupled to the laser generator, the laser detector, and the scanning apparatus. The controller is configured to characterize an internal feature of the structure based on the reflections.

(8) Another embodiment of the present disclosure is a method. The method includes generating, via a first plurality of beam splitters, a plurality of generation laser light beams from an emitted generation laser light. The method also includes generating, via a second plurality of beam splitters, a plurality of detection laser light beams from an emitted detection laser light. The method also includes, for each of a plurality of laser ultrasonic channels, (i) directing a respective one of the plurality of generation laser light beams and a respective one of the plurality of detection laser light beams to a surface of a structure via the laser ultrasonic channel and (ii) collecting one or more reflections of the respective one of the plurality of detection laser light beams via the laser ultrasonic channel. The method further includes characterizing an internal feature of the structure based on the reflections.

(9) Another embodiment of the present disclosure is a laser ultrasonic system. The laser ultrasonic system includes a scanning head and a robotic arm coupled to the scanning head. The scanning head includes a laser generator configured to emit generation laser light, and a laser detector configured to emit detection laser light. The scanning head is configured to receive the generation laser light and the detection laser light. The scanning head is also configured to direct the generation laser light and the detection laser light onto a surface of a structure via a plurality of laser ultrasonic channels. The scanning head is further configured to collect reflections of the detection laser light from the surface of the structure via the plurality of laser ultrasonic channels.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) So that the manner in which the above recited features can be understood in detail, a more particular description, briefly summarized above, may be had by reference to example embodiments, some of which are illustrated in the appended drawings.

(2) FIG. 1 is a block diagram illustrating an example testing environment, according to one embodiment.

(3) FIG. 2 illustrates an example scanning head for a laser ultrasonic system, according to one embodiment.

(4) FIG. 3 illustrates another example scanning head for a laser ultrasonic system, according to one embodiment.

(5) FIG. 4 illustrates another example scanning head for a laser ultrasonic system, according to one embodiment.

(6) FIG. 5 is a flowchart of a method for performing a laser ultrasonic test to inspect a structure, according to one embodiment.

(7) FIG. 6 illustrates an example testing environment, according to one embodiment.

DETAILED DESCRIPTION

(8) The present disclosure provides for ultrasound testing of various components using a laser ultrasonic (LUT) system, which includes multiple data acquisition channels, a single generation laser, and a single detection laser. In certain embodiments, the LUT system is used for ultrasonic inspection of polymer-matrix composites during aircraft manufacturing. The LUT system described herein can significantly increase ultrasonic inspection speeds when scanning composite materials, increase signal quality, and maintain the cost of inspection low, relative to conventional laser ultrasonic inspection systems.

(9) For example, in certain embodiments, the LUT system includes an inspection or scanning head that shares the generation and detection laser beams from a single generation laser and a single detection laser, respectively, among multiple channels. Using a single generation laser and a single detection laser enables a laser ultrasonic system to use higher quality, higher power lasers, while minimizing the capital cost per channel because the cost per unit of power is generally lower for

industrial lasers relative to smaller custom-type lasers or diode lasers. In particular, for multiple-channel LUT systems, if a single industrial laser can be shared between multiple channels, the total system cost for such an approach becomes similar to an approach that uses smaller lasers.

(10) Additionally, more power may be available with a LUT system with multiple channels, because industrial lasers have a lower cost per unit of laser power, relative to smaller lasers. More power, in turn, may translate into a higher quality signal (e.g., a larger signal-to-noise ratio (SNR)). The higher quality signals may translate into a better incidence angle tolerance and longer depth of fields, which in turn can result in a larger range of possible applications and higher manufacturing throughput.

(11) FIG. 1 is a block diagram illustrating an example testing environment **100**, according to certain embodiments. The testing environment **100** includes a LUT system **102**, which is used to test a structure **110**. The structure **110** is generally representative of any article or object that is to be tested using the LUT system **102**. For example, the structure **110** may include materials or components of an aircraft, vehicle, ship, or other structures.

(12) The LUT system **102** includes a controller **130**, a movement apparatus **140**, a (single) laser generator **154**, a (single) laser detector **156**, one or more optical fibers **158**, one or more optical fibers **152**, one or more interferometers **150**, and one or more optical fibers **160**. The controller **130** is generally configured to control one or more components of the LUT system **102**, including, for example, the movement apparatus **140**, laser generator **154**, laser detector **156**, and interferometer(s) **150**.

(13) The controller **130** includes a processor **132**, a memory **134**, and one or more input/output (I/O) devices **138**. The processor **132** is any electronic circuitry, including, but not limited to one or a combination of microprocessors, microcontrollers, application specific integrated circuits (ASIC), application specific instruction set processor (ASIP), and/or state machines, that communicatively couples to memory **134** and controls the operation of the LUT system **102**. The processor **132** may be 8-bit, 16-bit, 32-bit, 64-bit or of any other suitable architecture. The processor **132** may include an arithmetic logic unit (ALU) for performing arithmetic and logic operations, processor registers that supply operands to the ALU and store the results of ALU operations, and a control unit that fetches instructions from memory and executes them by directing the coordinated operations of the ALU, registers and other components. The processor **132** may include other hardware that operates software to control and process information. The processor **132** executes software stored on the memory **134** to perform any of the functions described herein. The processor **132** controls the operation and administration of the controller **130** by processing information (e.g., information received from the processor **132**, memory **134**, and/or I/O devices **138**). The processor **132** is not limited to a single processing device and may encompass multiple processing devices.

(14) The memory **134** may store, either permanently or temporarily, data, operational software, or other information for the processor **132**. The memory **134** may include any one or a combination of volatile or non-volatile local or remote devices suitable for storing information. For example, the memory **134** may include random access memory (RAM), read only memory (ROM), magnetic storage devices, optical storage devices, or any other suitable information storage device or a combination of these devices. The software represents any suitable set of instructions, logic, or code embodied in a computer-readable storage medium. For example, the software may be embodied in the memory **134**, a disk, a CD, or a flash drive. In particular embodiments, the software may include an application executable by the processor **132** to perform one or more of the functions described herein. Here, the memory **134** includes a data acquisition system **172**, which is described in greater detail herein. The I/O devices **138** may include, but are not limited to, one or more of a keypad, a keyboard, a touch-sensitive display screen, a liquid crystal display (LCD) screen, a microphone, a speaker, a communication port, or any combination thereof.

(15) The laser generator **154** is configured to emit generation laser light **144**. In certain embodiments, the generation laser light **144** emitted from the laser generator **154** is in the form of a

laser pulse. Note, however, that the laser generator **154** can emit generation laser light **144** with any duration, frequency, and power. The laser detector **156** is configured to generate detection laser light **148**. In certain embodiments, the laser detector **156** generates the detection laser light **148** to illuminate the surface **114** of the structure **110** where surface displacements associated with ultrasonic waves are expected to occur. The laser detector **156** can be a continuous laser or long pulsed laser. Note, however, that the laser detector **154** can emit detection laser light **148** with any duration, frequency, and power. In certain embodiments, one or more parameters of the generation laser light **144** and/or the detection laser light **148** may be based on the materials **112** used to form the structure **110**.

(16) The movement apparatus **140** includes a scanning head **142**, which is generally configured to position and focus the generation laser light **144** (emitted from the laser generator **154**) and the detection laser light **148** (emitted from the laser detector **156**) onto the structure **110**. The scanning head **142** may receive the generation laser light **144** via one or more optical fibers **158**, optics, or a combination thereof. Similarly, the scanning head **142** may receive the detection laser light **148** via one or more optical fibers **152**, optics, or a combination thereof. The scanning head **142** may include an optical scanner, a mirror scanner, or another type of scanner. In one embodiment, scanning head **142** may not include a scanner, in which case scanning may be accomplished by movement apparatus **140** moving scanning head **142**.

(17) In certain embodiments, one or more components of the LUT system **102** are mounted, or partially mounted, in the scanning head **142**. In one example, the scanning head **142** may include the laser generator **154** and the laser detector **156**. In another example, at least one of the laser generator **154** or the laser detector **156** can be partially mounted in the scanning head **142**. In another example, the laser generator **154** may receive the generation laser light **144** through optics, optical fiber(s) **158**, or a combination thereof, and the laser detector **156** may receive the detection laser light **148** through optics, optical fiber(s) **152**, or a combination thereof.

(18) The movement apparatus **140** can move the scanning head **142** in relation to the structure **110**. For example, the controller **130** can control the movement apparatus **140** so that the generation laser light **144** and detection laser light **148** moves over the structure **110** along a scan path **146**. In certain embodiments, the movement apparatus **140** is a robot, a robotic arm, or a gantry. In addition to, or as an alternative to, the movement apparatus **140** moving the scanning head **142**, the scanning head **142** can move the generation laser light **144** and/or the detection laser light **148** at the surface **114** of the structure **110** to inspect an area of the structure **110** for a given position of the scanning head **142**. In embodiments where the scanning head **142** is not able to perform scanning, the scanning may be achieved by movements of the movement apparatus **140**.

(19) In certain embodiments, the generation laser light **144** is absorbed at the surface **114** of the structure **110**. The absorption of the generation laser light **144** creates a sudden localized thermal expansion that sends ultrasonic waves **118** into the structure **110**. The ultrasonic waves **118** may be sent in a direction that is normal relative to the surface **114** of the structure **110**, notwithstanding the incidence angle of the generation laser light **144**.

(20) In certain embodiments, the detection laser light **148** illuminates the surface **114** of the structure **110** where surface displacements associated with the ultrasonic waves **118** are expected to occur. The detection laser light **148** is reflected off the surface **114** of the structure **110** (shown as reflected detection laser light **170**). The reflected detection laser light **170** may be collected by a set of collection optics (not shown) and may be received by one or more interferometers **150** via one or more optical fibers **160**. The interferometer(s) **150** may demodulate the reflected detection laser light **170** to extract an ultrasonic signal. The interferometer(s) **150** are representative of different types of interferometers, including, for example, confocal Fabry-Perot interferometers, photorefractive interferometers, and fiber-based Sagnac interferometers. The interferometer(s) **150** may be integral or external to the scanning head **142**. The controller **130**, via the data acquisition system **172**, may analyze the extracted ultrasonic signal to determine whether a defect is present in

the structure **110**.

(21) FIG. 2 illustrates an example scanning head **242** of a LUT system **102**, according to one embodiment. The scanning head **242** is an example implementation of the scanning head **142** illustrated in FIG. 1. In this embodiment, the laser generator **154** and the laser detector **156** are located within the scanning head **242**. In another embodiment, at least one of the laser generator **154** or the laser detector **156** is partially located in the scanning head **242**. In yet another embodiment, the laser generator **154** and the laser detector **156** are optically coupled using moving mirrors, articulated mirrors, or a combination of moving and articulated mirrors.

(22) As shown, the scanning head **242** includes multiple channels **210 1-N**. The generation laser light **144** emitted from the laser generator **154** is directed towards a (first) LUT channel **210-1**. A (first) generation beam splitter (GBS) **216-1** reflects a fraction of power of the original generation laser light **144** towards the surface **114** of the structure **110** through a (first) Dichroic **220-1** as generation laser light **144-1**, and the rest of the power of the generation laser light **144** is directed towards a (second) LUT channel **210-2**. A (second) GBS **216-2** reflects another fraction of the remaining power of the generation laser light **144** towards the surface **114** of the structure **110** through a (second) Dichroic **220-2** as generation laser light **144-2**, and the rest of the power of the power of the generation laser light **144** is directed towards a (third) LUT channel (not shown). This pattern is repeated until the remaining power of the generation laser light **144** reaches the last (N.sup.th) LUT channel **210-N**, where the generation laser light is completely reflected by a generation final mirror (GFM) **218** towards the surface **114** of the structure through a (N.sup.th) Dichroic **220-N** as generation laser light **144-N**.

(23) As also shown in FIG. 2, the detection laser light **148** emitted from the laser detector **156** is directed towards the (first) LUT channel **210-1**. A (first) detection beam splitter (DBS) **212-1** reflects a fraction of power of the original detection laser light **148** towards a (first) detection turning mirror (DTM) **222-1**, and the rest of the power of the detection laser light **148** is directed towards a (second) LUT channel **210-2**. The DTM **222-1** reflects the fraction of power of the original detection laser light **148** towards Dichroic **220-1**, which, in turn, reflects the fraction of power of the original detection laser light **148** towards the surface **114** of the structure **110** as detection laser light **148-1**.

(24) A (second) DBS **212-2** reflects another fraction of power of the remaining detection laser light **148** towards a (second) DTM **222-2**, and the rest of the power of the detection laser light **148** is directed towards a (third) LUT channel (not shown). The DTM **222-2** reflects the other fraction of power of the remaining detection laser light **148** towards Dichroic **220-2**, which, in turn, reflects the other fraction of power of the remaining detection laser light **148** towards the surface **114** of the structure **110** as detection laser light **148-2**. This pattern is repeated until the remaining power of the detection laser light **148** reaches the last (N.sup.th) LUT channel, where the detection laser light **148** is completely reflected by a detection final mirror (DFM) **214** towards an (N.sup.th) DTM **222-N**. The DTM **222-N** then reflects the remaining power of the detection laser light **148** towards Dichroic **220-N**, which, in turn, reflects the remaining power of the detection laser light **148** towards the surface **114** of the structure **110** as detection laser light **148-N**.

(25) The detection laser light **148 1-N** is scattered or reflected by the surface **114** as reflected detection laser light **170 1-N**, respectively. The reflected detection laser light **170 1-N** is reflected by the Dichroic **220 1-N** towards focusing optics (FO) **224 1-N**, respectively. The FO **224 1-N** focus the reflected detection laser light **170 1-N** into optical fibers **160 1-N**, respectively. The optical fibers **160 1-N** transmit the reflected detection laser light **170 1-N** to interferometers **150 1-N**, respectively. As noted, the interferometers **150** may be located within the scanning head **242**, within the movement apparatus **140**, or elsewhere within the testing environment **100**.

(26) In FIG. 2, the generation laser light **144** and detection laser light **148** of all the LUT channels **210** can be made collinear or non-collinear. In general, the generation laser light **144** and detection laser light **148** may form a pattern of inspection spots at the surface **114** of the structure **110**, such

that when a movement apparatus **140** moves the scanning head **142**, the inspection rate of the structure **110** is increased by a factor equal to the number of LUT channels **210** in the scanning head **142**, relative to a scanning head containing a single LUT channel.

(27) In certain embodiments, the DBSs **212** and GBSs **216** have different characteristics so that the power of the generation laser light **144** and power of the detection laser light **148** are approximately the same for all the LUT channels **210**. In general, the generation laser light **144** and detection laser light **148** can be varied in any suitable manner in order to create a target number of inspection spots at one or more target locations of the structure **110**.

(28) FIG. **3** illustrates an example scanning head **342** of a LUT system **102**, according to one embodiment. The scanning head **342** is an example implementation of the scanning head **142** illustrated in FIG. **1**. Compared to the scanning head **242**, the scanning head **342** does not include the laser generator **154** and the laser detector **156**. That is, the generation laser light **144** and the detection laser light **148** are not generated within the scanning head **342**.

(29) For example, as shown in FIG. **3**, the generation laser light **144** emitted from the laser generator **154** and the detection laser light **148** emitted from the laser detector **156** are brought to the scanning head **342** by optical fibers **158** and **152**, respectively. Once the generation laser light **144** and detection laser light **148** exit the optical fibers **158** and **152**, respectively, the generation laser light **144** and detection laser light **148** may follow a pattern similar to that depicted in FIG. **2**. Note that while FIG. **3** depicts both generation laser light **144** and detection laser light **148** being brought to the scanning head via respective optical fibers **158** and **152**, in certain embodiments, at least one of the generation laser light **144** or the detection laser light **148** may be brought to the scanning head **342** by a respective optical fiber.

(30) FIG. **4** illustrates an example scanning head **442** of a LUT system **102**, according to one embodiment. The scanning head **442** is an example implementation of the scanning head **142** illustrated in FIG. **1**. Compared to the scanning head **242**, the scanning head **442** does not include the laser generator **154** and the laser detector **156**. That is, the generation laser light **144** and the detection laser light **148** are not generated within the scanning head **342**. For example, as shown in FIG. **4**, at least one of the generation laser light **144** emitted from the laser generator **154** or the detection laser light **148** emitted from the laser detector **156** may be split and injected into a number of optical fibers equal to the number of LUT channels **210** in the scanning head **442**.

(31) In particular, the generation laser light **144** from the single laser generator **154** is distributed to each of the multiple channels **210** 1-N via respective optical fibers **158** 1-N. Similarly, the detection laser light **148** from the single laser detector **165** is distributed to each of the multiple channels **210** 1-N via respective optical fibers **152** 1-N. In this embodiment, each channel **210** is optically uncoupled from the other channels **210**.

(32) Note that the embodiments of the scanning head described in FIGS. **2**, **3**, and **4** are shown as reference examples of scanning heads **142** that may be used within LUT systems, and the scanning head **142** may have different configurations consistent with the functionality described herein. For example, in certain embodiments, a bundle of optical fibers may inject the generation laser light **144** or the detection laser light **148**, or both, in a predefined pattern onto a single mirror and single Dichroic. As another example, in certain embodiments, the shape of scanning head **142**, or the configuration of its optical components, or both, may be adapted to inspect structures **110** that have surfaces that might be more complex than just flat.

(33) FIG. **5** is a flowchart of a method **500** for performing a laser ultrasonic test to inspect a structure (e.g., structure **110**), according to one embodiment. Method **500** enters with block **502**, where a movement apparatus **140** (e.g., robot or gantry) positions the scanning head **142** with respect to the structure **110**. When the movement apparatus **140** has the desired position, the laser ultrasonic measurement (including data acquisition system **172**) is triggered (block **504**). At blocks **506** and **508**, the laser generator **154** and laser detector **156** emit respective generation laser light **144** and detection laser light **148**.

(34) At blocks **510** and **512**, the beams of the generation laser light **144** and detection laser light **148** are split into a number of laser light beams and a number of detection laser light beams, respectively. Each of the number of laser light beams and the number of detection laser light beams may correspond to the number of LUT channels **210**. At block **514**, each pair of generation laser light beam and detection laser light beam is directed into a respective LUT channel **210**.

(35) At block **516**, each LUT channel **210** directs its generation laser light beam and detection laser light beam towards the surface **114** of the structure **110** and collects the detection laser light beams reflected by the surface **114** of the structure **110**. At block **518**, each LUT channel **210** directs collected detection laser light beams to its corresponding interferometer **150**. Each interferometer **150** extracts ultrasonic information from the collected light, and sends the ultrasonic information to a data acquisition system **172** (block **520**). At block **522**, the digitized data of the data acquisition system **172** is sent to a data processing system that adds the data for the current inspection spots to the total inspection data for the current structure **110**. If the inspection is not completed, then the method **500** goes to block **502** to position the movement apparatus **140** to the next inspection location.

(36) FIG. **6** illustrates an example testing environment **600**, according to one embodiment. The testing environment **600** is an example implementation of the testing environment **100** depicted in FIG. **1**. Here, the testing environment **600** includes a robot **640**, which is used to move the scanning head **142** in relation to the structure **110**. The robot **640** is one example implementation of the movement apparatus **140**. The scanning head **142** is generally representative of any of the scanning heads described herein, including, for example scanning head **242**, **342**, and **442**.

(37) A further understanding of at least some of the aspects of the present disclosure is provided with reference to the following numbered Clauses, in which: Clause 1: A system comprising: a laser generator configured to emit generation laser light; a laser detector configured to emit detection laser light; a scanning apparatus configured to: receive the generation laser light and the detection laser light; direct the generation laser light and the detection laser light onto a surface of a structure via a plurality of laser ultrasonic channels; and collect reflections of the detection laser light from the surface of the structure via the plurality of laser ultrasonic channels; and a controller coupled to the laser generator, the laser detector and the scanning apparatus, the controller being configured to characterize an internal feature of the structure based on the reflections. Clause 2: The system of Clause 1, wherein: the scanning apparatus comprises a plurality of beam splitters and a plurality of dichroics; and in order to direct the generation laser light onto the surface of the structure, each beam splitter is configured to reflect a respective portion of the generation laser light onto the surface of the structure via a respective dichroic of the plurality of dichroics. Clause 3: The system of Clause 2, wherein each beam splitter is configured to reflect a different portion of the generation laser light onto a different laser ultrasonic channel of the plurality of laser ultrasonic channels. Clause 4: The system of any of Clauses 1 to 3, wherein the scanning apparatus further comprises a mirror configured to reflect a remaining portion of the generation laser light onto the surface of the structure. Clause 5: The system of any of Clauses 1 to 4, wherein: the scanning apparatus comprises a plurality of beam splitters, a plurality of first mirrors, and a plurality of dichroics; and in order to direct the detection laser light onto the surface of the structure: each beam splitter is configured to reflect a respective portion of the detection laser light onto a respective dichroic of the plurality of dichroics via a respective one of the plurality of first mirrors; and each respective dichroic is configured to direct the respective portion of the detection laser light onto the surface of the structure. Clause 6: The system of Clause 5, wherein each beam splitter is further configured to reflect a different portion of the detection laser light onto a different laser ultrasonic channel of the plurality of laser ultrasonic channels. Clause 7: The system of any of Clauses 5 to 6, wherein the scanning apparatus further comprises a second mirror configured to reflect a remaining portion of the detection laser light onto the surface of the structure. Clause 8: The system of any of Clauses 5 to 7, wherein in order to collect the reflections of the detection laser light from the

surface of the structure, each dichroic is configured to receive a different portion of the reflections of the detection laser light from the surface of the structure. Clause 9: The system of any of Clauses 1 to 8, further comprising a plurality of interferometers, each interferometer being configured to receive a respective portion of the reflections from a respective laser ultrasonic channel of the plurality of laser ultrasonic channels. Clause 10: The system of any of Clauses 1 to 9, wherein the scanning apparatus is configured to, for each laser ultrasonic channel of the plurality of laser ultrasonic channels: direct a different portion of the generation laser light to the laser ultrasonic channel via a respective optical fiber of a first plurality of optical fibers; and direct a different portion of the detection laser light to the laser ultrasonic channel via a respective optical fiber of a second plurality of optical fibers. Clause 11: The system of any of Clauses 1 to 10, wherein the scanning apparatus comprises the laser generator and the laser detector. Clause 12: The system of any of Clauses 1 to 10, wherein the scanning apparatus is configured to: receive the generation laser light via a first optical fiber and receive the detection laser light via a second optical fiber; direct the generation laser light to a first laser ultrasonic channel of the plurality of laser ultrasonic channels via the first optical fiber; and direct the detection laser light to the first laser ultrasonic channel via the second optical fiber. Clause 13: The system of any of Clauses 1 to 12, further comprising a movement apparatus configured to move the scanning apparatus relative to the surface of the structure. Clause 14: A method, comprising: generating, via a first plurality of beam splitters, a plurality of generation laser light beams from an emitted generation laser light; generating, via a second plurality of beam splitters, a plurality of detection laser light beams from an emitted detection laser light; for each of a plurality of laser ultrasonic channels, (i) directing a respective one of the plurality of generation laser light beams and a respective one of the plurality of detection laser light beams to a surface of a structure via the laser ultrasonic channel and (ii) collecting one or more reflections of the respective one of the plurality of detection laser light beams via the laser ultrasonic channel; and characterizing an internal feature of the structure based on the reflections. Clause 15: The method of Clause 14, wherein the plurality of generation laser light beams and the plurality of detection laser light beams are generated within a scanning apparatus. Clause 16: The method of any one of Clauses 14 to 15, wherein at least one of the generation laser light or the detection laser light is emitted within the scanning apparatus. Clause 17: The method of any one of Clauses 14 to 16, wherein the generation laser light is directed to an initial laser ultrasonic channel of the plurality of laser ultrasonic channels via an optical fiber. Clause 18: The method of any one of Clauses 14 to 17, wherein the detection laser light is directed to an initial laser ultrasonic channel of the plurality of ultrasonic channels via an optical fiber. Clause 19: The method of any of Clauses 14 to 16, wherein, for each of the plurality of laser ultrasonic channels, the respective one of the plurality of generation laser light beams is directed to the laser ultrasonic channel via a respective first optical fiber and the respective one of the plurality of detection laser light beams is directed to the laser ultrasonic channel via a respective second optical fiber. Clause 20: A laser ultrasonic system comprising: a scanning head; and a robotic arm coupled to the scanning head, wherein: the scanning head comprises: a laser generator configured to emit generation laser light; and a laser detector configured to emit detection laser light; and the scanning head is configured to: receive the generation laser light and the detection laser light; direct the generation laser light and the detection laser light onto a surface of a structure via a plurality of laser ultrasonic channels; and collect reflections of the detection laser light from the surface of the structure via the plurality of laser ultrasonic channels.

(38) In the current disclosure, reference is made to various aspects. However, it should be understood that the present disclosure is not limited to specific described aspects. Instead, any combination of the following features and elements, whether related to different aspects or not, is contemplated to implement and practice the teachings provided herein. Additionally, when elements of the aspects are described in the form of “at least one of A and B,” it will be understood that aspects including element A exclusively, including element B exclusively, and including

element A and B are each contemplated. Furthermore, although some aspects may achieve advantages over other possible solutions and/or over the prior art, whether or not a particular advantage is achieved by a given aspect is not limiting of the present disclosure. Thus, the aspects, features, aspects and advantages disclosed herein are merely illustrative and are not considered elements or limitations of the appended claims except where explicitly recited in a claim(s). Likewise, reference to “the invention” shall not be construed as a generalization of any inventive subject matter disclosed herein and shall not be considered to be an element or limitation of the appended claims except where explicitly recited in a claim(s).

(39) As will be appreciated by one skilled in the art, aspects described herein may be embodied as a system, method or computer program product. Accordingly, aspects may take the form of an entirely hardware aspect, an entirely software aspect (including firmware, resident software, micro-code, etc.) or an aspect combining software and hardware aspects that may all generally be referred to herein as a “circuit,” “module” or “system.” Furthermore, aspects described herein may take the form of a computer program product embodied in one or more computer readable storage medium(s) having computer readable program code embodied thereon.

(40) Program code embodied on a computer readable storage medium may be transmitted using any appropriate medium, including but not limited to wireless, wireline, optical fiber cable, RF, etc., or any suitable combination of the foregoing.

(41) Computer program code for carrying out operations for aspects of the present disclosure may be written in any combination of one or more programming languages, including an object oriented programming language such as Java, Smalltalk, C++ or the like and conventional procedural programming languages, such as the “C” programming language or similar programming languages. The program code may execute entirely on the user's computer, partly on the user's computer, as a stand-alone software package, partly on the user's computer and partly on a remote computer or entirely on the remote computer or server. In the latter scenario, the remote computer may be connected to the user's computer through any type of network, including a local area network (LAN) or a wide area network (WAN), or the connection may be made to an external computer (for example, through the Internet using an Internet Service Provider).

(42) Aspects of the present disclosure are described herein with reference to flowchart illustrations and/or block diagrams of methods, apparatuses (systems), and computer program products according to aspects of the present disclosure. It will be understood that each block of the flowchart illustrations and/or block diagrams, and combinations of blocks in the flowchart illustrations and/or block diagrams, can be implemented by computer program instructions. These computer program instructions may be provided to a processor of a general purpose computer, special purpose computer, or other programmable data processing apparatus to produce a machine, such that the instructions, which execute via the processor of the computer or other programmable data processing apparatus, create means for implementing the functions/acts specified in the block(s) of the flowchart illustrations and/or block diagrams.

(43) These computer program instructions may also be stored in a computer readable medium that can direct a computer, other programmable data processing apparatus, or other device to function in a particular manner, such that the instructions stored in the computer readable medium produce an article of manufacture including instructions which implement the function/act specified in the block(s) of the flowchart illustrations and/or block diagrams.

(44) The computer program instructions may also be loaded onto a computer, other programmable data processing apparatus, or other device to cause a series of operational steps to be performed on the computer, other programmable apparatus or other device to produce a computer implemented process such that the instructions which execute on the computer, other programmable data processing apparatus, or other device provide processes for implementing the functions/acts specified in the block(s) of the flowchart illustrations and/or block diagrams.

(45) The flowchart illustrations and block diagrams in the Figures illustrate the architecture,

functionality, and operation of possible implementations of systems, methods, and computer program products according to various aspects of the present disclosure. In this regard, each block in the flowchart illustrations or block diagrams may represent a module, segment, or portion of code, which comprises one or more executable instructions for implementing the specified logical function(s). It should also be noted that, in some alternative implementations, the functions noted in the block may occur out of the order noted in the Figures. For example, two blocks shown in succession may, in fact, be executed substantially concurrently, or the blocks may sometimes be executed in the reverse order or out of order, depending upon the functionality involved. It will also be noted that each block of the block diagrams and/or flowchart illustrations, and combinations of blocks in the block diagrams and/or flowchart illustrations, can be implemented by special purpose hardware-based systems that perform the specified functions or acts, or combinations of special purpose hardware and computer instructions.

(46) While the foregoing is directed to aspects of the present disclosure, other and further aspects of the disclosure may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

Claims

1. A system comprising: a laser generator configured to emit generation laser light; a laser detector configured to emit detection laser light; a scanning head configured to: receive the generation laser light and the detection laser light; direct the generation laser light and the detection laser light onto a surface of a structure via a plurality of laser ultrasonic channels; and collect reflected detection laser light from the surface of the structure via the plurality of laser ultrasonic channels; a plurality of interferometers; and a controller coupled to the laser generator, the laser detector, and the interferometers, the controller being configured to characterize an internal feature of the structure based on the reflected detection laser light, wherein the scanning head comprises: a plurality of generation beam splitters; a plurality of detection beam splitters; a plurality of detection turning mirrors; a plurality of dichroics; and a plurality of focusing optics; wherein, in order for the scanning head to direct the generation laser light and the detection laser light onto a plurality of locations on the surface of the structure via the plurality of laser ultrasonic channels: each one of the plurality of generation beam splitters is configured to reflect a portion of the generation laser light along one of the plurality of laser ultrasonic channels to one of the plurality of dichroics and another portion of the generation laser light to another one of the plurality of generation beam splitters; each one of the plurality of detection beam splitters is configured to reflect a portion of the detection laser light along one of the plurality of laser ultrasonic channels to one of the plurality of detection turning mirrors and another portion of the detection laser light to another one of the plurality of detection beam splitters; each one of the plurality of detection turning mirrors is configured to reflect the portion of the detection laser light along the one of the plurality of laser ultrasonic channels to the one of the plurality of dichroics; and each one of the plurality of dichroics is configured to reflect the portion of the generation laser light along the one of the plurality of laser ultrasonic channels to one of the plurality of locations on the surface of the structure and the portion of the detection laser light along the one of the plurality of laser ultrasonic channels to the one of the plurality of locations on the surface of the structure; and wherein, in order for the scanning head to collect the reflected detection laser light from the plurality of locations on the surface of the structure via the plurality of laser ultrasonic channels: each one of the plurality of dichroics is configured to reflect a portion of the reflected detection laser light from the one of the plurality of locations on the surface of the structure along the one of the plurality of laser ultrasonic channels to one of the plurality of focusing optics; and each one of the plurality of focusing optics is configured to reflect the portion of the reflected detection laser light along the one of the plurality of laser ultrasonic channels to one of the plurality of interferometers.

2. The system of claim 1, wherein each one of the plurality of generation beam splitters is configured to reflect a different portion of the generation laser light onto a different laser ultrasonic channel of the plurality of laser ultrasonic channels.
3. The system of claim 1, wherein each one of the plurality of dichroics is configured to receive a different portion of the reflected detection laser light from a different one of the plurality of locations on the surface of the structure.
4. The system of claim 1, wherein each one of the plurality of interferometers is configured to receive a respective portion of the reflected detection laser light from a respective one of the plurality of dichroics along a respective laser ultrasonic channel of the plurality of laser ultrasonic channels.
5. The system of claim 1, wherein the laser generator and the laser detector are remote from and optically coupled to the scanning head.
6. The system of claim 5, wherein the scanning head is configured to: receive the generation laser light from the laser generator via a first optical fiber; and receive the detection laser light from the laser detector via a second optical fiber.
7. The system of claim 1, further comprising a movement apparatus configured to move the scanning head relative to the surface of the structure.
8. The system of claim 1, wherein each one of the plurality of detection beam splitters is configured to reflect a different portion of the detection laser light onto a different laser ultrasonic channel of the plurality of laser ultrasonic channels.
9. The system of claim 1, wherein the laser generator and the laser detector are coupled directly to the scanning head.
10. A method, comprising: receiving, by a scanning head, generation laser light; receiving, by the scanning head, detection laser light; directing the generation laser light and the detection laser light onto a plurality of locations on a surface of a structure via a plurality of laser ultrasonic channels by: reflecting, by each one of a plurality of generation beam splitters, a portion of the generation laser light along an associated one of the plurality of laser ultrasonic channels to an associated one of a plurality of dichroics and another portion of the generation laser light to another one of the plurality of generation beam splitters; reflecting, by each one of a plurality of detection beam splitters, a portion of the detection laser light along an associated one of the plurality of laser ultrasonic channels to an associated one of a plurality of detection turning mirrors and another portion of the detection laser light to another one of the plurality of detection beam splitters; reflecting, by each one of a plurality of detection turning mirrors, the portion of the detection laser light along the associated one of the plurality of laser ultrasonic channels to the associated one of the plurality of dichroics; and reflecting, by each one of the plurality of dichroics, the portion of the generation laser light along the associated one of the plurality of laser ultrasonic channels to an associated one of the plurality of locations on the surface of the structure and the portion of the detection laser light along the associated one of the plurality of laser ultrasonic channels to the associated one of the plurality of locations on the surface of the structure; collecting reflected detection laser light from each one of the plurality of locations on the surface of the structure via the plurality of laser ultrasonic channels by: reflecting, by each one of the plurality of dichroics, a portion of reflected detection laser light from the associated one of the plurality of locations on the surface of the structure along the associated one of the plurality of laser ultrasonic channels to an associated one of a plurality of focusing optics; and reflecting, by each one of the plurality of focusing optics, the portion of the reflected detection laser light along the associated one of the plurality of laser ultrasonic channels to an associated one of a plurality of interferometers; and characterizing an internal feature of the structure based on the reflected detection laser light.
11. The method of claim 10, wherein the generation laser light and the detection laser light are generated within the scanning head.
12. The method of claim 10, wherein one of the generation laser light or the detection laser light is

generated within the scanning apparatus head.

13. The method of claim 10, wherein the generation laser light is directed to the scanning head via an optical fiber.

14. The method of claim 10, wherein the detection laser light is directed to the scanning head via an optical fiber.

15. The method of claim 10, wherein a plurality of portions of the reflected detection laser light is directed to each one of the plurality of interferometers via a plurality of optical fibers.

16. The method of claim 10, further comprising forming each one of the plurality of laser ultrasonic channels comprising associated ones of the generation beam splitters, detection beam splitters, detection turning mirrors, dichroics, and focusing optics.

17. A laser ultrasonic scanning system comprising: a scanning head comprising: a plurality of generation beam splitters configured to receive generation laser light from a laser generator; a plurality of detection beam splitters configured to receive detection laser light from a laser detector; a plurality of detection turning mirrors, each in optical communication with one of the plurality of detection beam splitters; a plurality of dichroics, each in optical communication with one of the plurality of generation beam splitters and one of the plurality of detection turning mirrors; and a plurality of focusing optics, each in optical communication with one of the plurality of dichroics, wherein associated ones of the generation beam splitters, detection beam splitters, detection turning mirrors, dichroics, and focusing optics form each one of a plurality of laser ultrasonic channels; wherein in order for the scanning head to direct the generation laser light and the detection laser light onto a plurality of locations on the surface of the structure via the plurality of laser ultrasonic channels: each one of the plurality of generation beam splitters is configured to reflect a portion of the generation laser light along one of the plurality of laser ultrasonic channels to one of the plurality of dichroics and another portion of the generation laser light to another one of the plurality of generation beam splitters; each one of the plurality of detection beam splitters is configured to reflect a portion of the detection laser light along one of the plurality of laser ultrasonic channels to one of the plurality of detection turning mirrors and another portion of the detection laser light to another one of the plurality of detection beam splitters; each one of the plurality of detection turning mirrors is configured to reflect the portion of the detection laser light along the one of the plurality of laser ultrasonic channels to the one of the plurality of dichroics; and each one of the plurality of dichroics is configured to reflect the portion of the generation laser light along the one of the plurality of laser ultrasonic channels to one of the plurality of locations on the surface of the structure and the portion of the detection laser light along the one of the plurality of laser ultrasonic channels to the one of the plurality of locations on the surface of the structure; and wherein, in order for the scanning head to collect the reflected detection laser light from the plurality of locations on the surface of the structure via the plurality of laser ultrasonic channels: each one of the plurality of dichroics is configured to reflect a portion of the reflected detection laser light from the one of the plurality of locations on the surface of the structure along the one of the plurality of laser ultrasonic channels to one of the plurality of focusing optics; and each one of the plurality of focusing optics is configured to reflect the portion of the reflected detection laser light along the one of the plurality of laser ultrasonic channels to one of the plurality of interferometers.

18. The system of claim 17, wherein the scanning head is configured to: receive the generation laser light from the laser generator via a first optical fiber; and receive the detection laser light from the laser detector via a second optical fiber.

19. The system of claim 17, further comprising further comprising a movement apparatus configured to move the scanning head relative to the surface of the structure.

20. The system of claim 17, further comprising a data acquisition system configured to extract and analyze ultrasonic signals from the reflected detection laser light.
