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(54) SYSTEM FOR AUTOMATED IN-PROCESS INSPECTION OF WELDS

SYSTEM ZUR AUTOMATISIERTEN INSPEKTION VON SCHWEISSNÄHTEN WÄHREND DER PRODUKTION

SYSTÈME D’INSPECTION AUTOMATISÉE DE SOUDURES EN COURS DE PRODUCTION

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Description

BACKGROUND OF THE INVENTION

[0001] The invention relates to weld quality control and, more particularly, to in-process inspection of automated welding processes.

[0002] Manufacturers of turbine rotors and similar devices may utilize gas-tungsten-arc welding of component parts. Such welding improves mechanical properties including the ability to join components having different base materials as is often desirable in high-performance machines. Welding a turbine rotor, however, can take dozens of hours, and in order for the weld operators to identify a potential problem (e.g., a pore, lack of fusion, large silicate island, etc.) before it is welded over on the next pass, the operators must pay careful attention to every pulse made by their torch. It is a difficult task for a human operator to pay such close attention for such a long period of time.

[0003] Even assuming the weld operators may be capable of paying such close attention, weld operators typically do not have the experience to know exactly what they are looking for. An experienced welder may see features in the shape of the molten pool, the sidewall wetting geometry, the solidified ripple pattern and the solidified bead geometry that comparative amateurs do not see.

[0004] Most weld defects - e.g., pores, inclusions, lack of fusion, etc. - cannot be detected until testing such as ultrasonic testing is conducted on a finished weld. Detecting weld defects at the time they are created would save significant costs and cycle time. It would thus be desirable to utilize a "tireless" computer to pay close attention to the millions of weld pulses over the course of several days that it takes to weld a turbine rotor. It would further be desirable to utilize a machine vision system that is properly trained to watch these critical welds.

[0005] US2004/0124227 A1 describes a device for monitoring the state of a welding work portion by taking an image thereof by an image sensor. The monitoring device provides an image clearly showing both the very bright welding portion and the dark bead portion with a sufficient contrast.

[0006] JP 2009 125 790 A describes an apparatus for reliably detecting various welding states such as a state of arc generation, a state of molten pool and a shape of bead after welding. The apparatus comprises two imaging means to image a circumference of arc weld, band-pass filters which are installed in an imaging range of one of the imaging means and have band-pass properties in an infrared light wavelength region and in an ultraviolet light wavelength region, illuminating means having an emission spectrum of ultraviolet light wavelength region and an image composing means to compose images taken by both imaging means and an image display to display the image composed by the image composing means.

[0007] US2015/0056585 A1 describes a system and method for monitoring manual welding which provide useful information to a welding trainee in real-time. In a numerical quality simulation a probability of defect formation is determined.

BRIEF SUMMARY OF THE INVENTION

[0008] In an example (not claimed) a method of detecting weld defects in real time includes a step of conducting a mock-up welding operation in a learning phase. The mock-up welding operating includes the steps of welding a first part to a second part, capturing images of a weld molten pool, and capturing images of a weld ripple shape and fillet geometry. The captured images are correlated with a weld position, and weld testing is performed on a weld resulting from the mock-up welding operation. Any defects in the weld are characterized, and the characterized defects are correlated with deviations in the captured images. During a production weld operation, the first camera captures images of a production weld molten pool, and the second camera captures images of a product weld ripple shape and fillet geometry. The captured images are processed to compute an aggregate probability that a weld position corresponding to the captured images contains a defect based on the correlated characterized defects.

[0009] In an embodiment, a method of detecting weld defects in real time includes the steps of (a) correlating potential weld defects with images of a mock weld molten pool and images of a mock weld ripple shape and fillet geometry; (b) depositing weld metal into an annular groove in a production weld operation; (c) a first camera capturing images of a production weld molten pool during the production weld operation; (d) a second camera capturing images of a production weld ripple shape and fillet geometry during the production weld operation; and (e) processing the images captured in (c) and (d) and computing an aggregate probability that a weld position corresponding to the images captured in (c) and (d) contains a defect based on the potential defects correlated in (a). The exact features of the claimed method are defined in appended claim 1.

[0010] In another embodiment, a system for detecting weld defects in real time includes a welding torch that enables weld metal to be deposited into an annular groove in a production weld operation, and first and second cameras. The first camera is positioned adjacent the welding torch and adjacent a part to be welded and captures images of a production weld molten pool during the production weld operation. The second camera is positioned farther from the welding torch than the first camera and downstream from the welding torch and captures images of a production weld ripple shape and fillet geometry during the production weld operation. A processor receives the images captured by the first and second cameras. The processor communicates with a database that stores correlated potential weld defects with images of a mock weld molten pool and images of a mock weld ripple shape and fillet geometry. The processor is programmed to process the images captured by the first and second cameras and to compute an aggregate probability that a weld position corresponding to the images captured by the first and second cameras contains a defect based on the potential defects correlated in the database. The exact features of the claimed system are defined in appended claim 13.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011]

FIGS. 1 and 2 are schematic illustrations showing the components for automated in-process inspection of welds;

FIG. 3 is a flow diagram of the method for detecting weld defects in real time;

FIG. 4 is an exemplary image of a weld molten pool; and

FIGS. 5-6 are exemplary images of a weld ripple shape and fillet geometry.

DETAILED DESCRIPTION OF THE INVENTION

[0012] The system performs in-process (i.e., real-time) inspection of automated welding processes such as a process for welding a turbine rotor. As described in more detail below, the system includes digital cameras that collect video data in real-time, sensors that monitor process data (amps, volts, temperatures, etc.) in real-time, and an inspection/testing system that is used off-line during a learning phase. During the learning phase, the system correlates features in the video and process data with defects and "indications" detected by testing. In operation, the system analyzes real-time streams and computes a probability at any given moment that a defect has been created. Based on configurable probability thresholds, welding can be suspended for re-work as soon as the system detects a high probability that a defect has been produced.

[0013] FIGS. 1 and 2 are schematic diagrams of the system for detecting weld defects in real-time. For purposes of the present description, weld metal is deposited into an annular groove 12 between a first part 14 and a second part 16. One or more welding torches 18, such as TIG (tungsten inert gas) welding torches for example, may be positioned adjacent the groove 12. In some embodiments, the welding torches 18 are held stationary, while the first and second parts 14, 16 are rotated. Alternatively, the welding torches 18 may be displaced circumferentially around the groove 12. The welding torches 18 include known sensors for weld data to measure physical characteristics of the weld, including, without limitation, gas flow values, temperature, welding current, voltage between torch and metal, circumferential position, radial position, etc.

[0014] A first camera 20 is positioned adjacent each welding torch 18 near the annular groove 12. A second camera 22 is positioned generally farther from each welding torch 18 than the first cameras 20 and downstream from the welding torches 18. By virtue of their proximity to the weld, the first cameras 20 must be able to withstand the high temperatures near the welding torches 18. The second cameras 22 are positioned farther from the heat generated by the torches 18 and thus do not require the same degree of heat resistance. The cameras 20, 22 capture digital video data at different stages of the weld process. Such cameras are known and available off-the-shelf, and further details of their structure and operation will not be described.

[0015] A processor 24 receives the images captured by the first and second cameras 20, 22 as well as the weld data. A database 26 communicates with the processor 24 and stores correlated potential weld defects with images of a mock weld molten pool and images of a mock weld ripple shape and fillet geometry from a learning phase (described below).

[0016] The first cameras 20 capture images including the edges of the molten weld pool, and the second cameras 22 capture downstream images of the solidified weld ripple and fillet geometry. Additional first cameras may be utilized to capture images of both the leading edge of the molten pool and the trailing edge of the molten pool. Sensors associated with the torches 18 collect the weld process data. The cameras 20, 22 may work with various wavelengths of light (infrared, visible, etc.). As each frame, or a subset of the incoming frames, of video is collected, algorithms parameterize the weld pool shape, the shape and location of refractory contaminants ("silicates" etc.) floating on the pool, solidified ripple shape and fillet geometry, and so on. Parameterization is done using best-fit polynomials or other functions.

[0017] As a non-limiting example, edge-detection operators such as the well-known "Canny algorithm" may be used on frames of video to locate the boundaries of the weld pool, as illustrated by the curved white lines in FIG. 4. In terms of a suitable x-y coordinate system, the white lines delineating the leading edge of the weld pool in FIG. 4 are fit to a mathematical function such as an Nth-order polynomial. The mathematical fit parameters that approximate the shape of the leading edge of the pool in one video frame are compared with fit parameters of the same feature from reference ("learning phase") video and/or adjacent frames in the same video. Deviations from the norm, or unexpected sudden changes in the fit parameters are used to identify and quantify anomalous situations.

[0018] Process and video data are indexed to the weld position. In an exemplary application to the turbine rotor weld, weld metal is deposited in dozens of overlapping passes by the torches 18 that fill the annular groove 12 outward. In this context, weld position is determined by a circumferential angle and a radial depth.

[0019] With reference to FIG. 3, during a learning phase (Step S1), a mock welding operation is conducted

(S2). The first camera 20 captures images of the weld molten pool, and the second camera 22 captures images of the weld ripple shape and fillet geometry (S3). The captured images are correlated with a weld position (S4), and weld testing is performed on the resulting mock weld. The welds may be inspected off-line by ultrasonic testing and/or destructive methods to characterize any contained defect indications. For example, the testing can determine at each weld position defect size, type (pore, inclusion, lack of fusion, etc.), orientation (radial-axial, radial-circumferential, etc.), location (sidewall, surface-connected, etc.), etc. Analytical algorithms correlate features in the parameterized video and process data with indications observed by inspection. FIGS. 5 and 6 are exemplary images of a weld ripple shape and fillet geometry. As an example, the release of a refractory silicate island disrupts the clean, consistent 2:00-to-8:00 ripple pattern shown in FIG. 5, and significantly alters the polynomial-fit parameters that best characterize this shape. Such a silicate also appears as a large axial-circumferential defect in an ultrasonic inspection. The magnitude of a deviation in fit parameters is correlated with the defect size determined by ultrasonic inspection of a defect at the same location in a given weld during the learning phase. This correlation forms the basis of the probabilistic estimate that a defect has been produced during the production phase of the system. Defects in the weld are characterized (S5). That is, they are sized by ultrasonic methods and/or exposed and measured by destructive methods such as metallography. The characterized defects are correlated or matched with deviations in the captured images (S6).

[0020] During the production weld process, weld defects are detected in real-time. While the production weld is formed (S8), the first and second cameras 20, 22 capture images of the production weld molten pool and the production weld ripple shape and fillet geometry, respectively (S9). The captured images are processed relative to, among other things, the images and correlations processed during the learning phase (S10), and an aggregate probability that a weld position corresponding to the captured images contains a defect is computed based on the characterized defects correlated at least in the learning phase (S11). Aggregate probability is a blended, weighted probability based on image analysis from the several cameras, as well as the process-parameter data gathered by the weld station. As a simplistic, non-limiting example, a sudden change in arc-voltage corresponding to a change in the distance between the tungsten and the workpiece may indicate a 20% chance that a silicate defect has been produced; meanwhile, video analysis may suggest a 35% chance that a silicate has been produced. In isolation, either of these two data points may not be sufficient to warrant investigation by the welders, but a near-simultaneous occurrence of these two events increases the aggregate probability tremendously.

[0021] It is possible during the learning phase to deliberately run the welding process outside normal parameters and artificially create defects to help train the system. In some cases, such as an inclusion produced when a silicate is shed from the weld pool and later welded over, the task of correlating video and process data with embedded defects has a high level of accuracy, leading to high-probability links between the data and the defect. In other cases, such as the subtle stack-up of several weld parameters that cause a sidewall lack of fusion, may be more difficult to identify by analytics, leading to low-probability correlations.

[0022] During production welding, the system computes an aggregate probability, in real-time, that a given weld position contains a defect. The system is configured to raise alarms or possibly shut down welding depending on the likelihood that a defect has been created. The system defines threshold shape deviations for the weld molten pool (edges) and the weld ripple shape and fillet geometry. FIG. 4 is an exemplary camera image of the weld molten pool, showing the system identifying a shape of the edges via image processing. FIGS. 5 and 6 are exemplary views of the weld ripple shape and fillet geometry being identified by the system in real-time. When the thresholds are exceeded, the system identifies a potential weld defect. Most critical welds that could benefit from this system involve post-weld nondestructive testing. It is thus possible to continue the learning phase and refine the system calculation tools after each production weld. That is, each set of data can be correlated with video and process data to improve the tools for identifying weld defects.

[0023] The system improves the probability of defect detection, enabling operators to push flaw-size "envelopes" with more confidence that critical flaws will not escape the production facility. Additionally, the cycle time to repair a defect can be reduced from several weeks or more to as little as a few minutes. Still further, the system can permit the use of less experienced welders and/or can enable welding by fewer operators.

[0024] While the invention has been described in connection with what is presently considered to be the most practical and preferred embodiments, it is to be understood that the invention is not to be limited to the disclosed embodiments, but on the contrary, is intended to cover various modifications and equivalent arrangements included within the scope of the appended claims.

Claims

1. A method of detecting weld defects in real time, the method comprising:

(a) correlating potential weld defects with images of a mock weld molten pool and images of a mock weld ripple shape and fillet geometry;
(b) depositing weld metal into an annular groove (12) in a production weld operation;
(c) a first camera (20) capturing images of a pro-

duction weld molten pool during the production weld operation;
(d) a second camera (22) capturing images of a production weld ripple shape and fillet geometry during the production weld operation; and
(e) processing the images captured in (c) and (d) and computing an aggregate probability that a weld position corresponding to the images captured in (c) and (d) contains a defect based on the potential defects correlated in (a).

2. A method of claim 1, wherein step (e) is practiced by analyzing an edge shape of the production weld molten pool.

3. A method of claim 1 or 2, wherein step (e) is practiced by analyzing a leading edge shape of the production weld molten pool and a trailing edge shape of the production weld molten pool.

4. The method according to any one of the preceding claims, **characterized in that** (a) correlating potential weld defects with images of a mock weld molten pool and images of a mock weld ripple shape and fillet geometry comprises by:

(a) conducting a mock-up welding operation in a learning phase including,

(1) using a welding torch, welding a first part (14) to a second part (16),
(2) a first camera (20) capturing images of a weld molten pool,
(3) a second camera (22) capturing images of a weld ripple shape and fillet geometry,
(4) correlating the images captured in (2) and (3) with a weld position,
(5) performing weld testing on a weld resulting from the welding in (1) and characterizing any defects in the weld, and
(6) correlating the characterized defects with deviations in the images captured in (2) and (3).

5. A method of claim 1, further comprising, after step (e) of claim 1, outputting an alert or disabling the production weld operation based on the aggregate probability.

6. A method of claim 4 or claim 5, wherein step (a)(6) of claim 4 is practiced by parameterizing a shape of the weld molten pool and the weld ripple shape and fillet geometry.

7. A method of claim 6, further comprising, before step (a)(4) of claim 4, capturing images of a shape and location of refractory contaminants in the weld motel pool, and wherein step (a)(6) further comprises parameterizing the shape and location of the refractory contaminants.

8. A method of any one of the preceding claims 4 to 7, further comprising repeating steps (a)(2)-(a)(6) of claim 4 using the images captured in (c) and (d) of claim 1.

9. A method of claim 1, wherein the production weld operation is performed by depositing weld metal in a plurality of overlapping passes by TIG torches that fill an annular groove (12) in a turbine rotor, and wherein the weld position is determined by a circumferential angle and a radial depth.

10. A method of claim 4, wherein step (a)(5) of claim 4 is practiced offline by ultrasonic testing or by destructive testing methods.

11. A method of claim 4, wherein step (a)(1) of claim 4is practiced to deliberately perform the welding step outside of normal parameters to artificially create defects.

12. A method of claim 4, wherein step (a)(6) of claim 4 is practiced by defining threshold shape deviations for the weld molten pool and the weld ripple shape and fillet geometry.

13. A system for detecting weld defects in real time, the system comprising:

a welding torch (18) configured to enable weld metal to be deposited into an annular groove (12) in a production weld operation;
a first camera (20) positioned adjacent the welding torch and adjacent a part to be welded, the first camera being configured to capture images of a production weld molten pool during the production weld operation;
a second camera (22) positioned farther from the welding torch than the first camera and downstream from the welding torch, the second camera being configured to capture images of a production weld ripple shape and fillet geometry during the production weld operation;
a processor (24) configured to receive the images captured by the first and second cameras; and
a database (26) having stored therein correlated potential weld defects with images of a mock weld molten pool and images of a mock weld ripple shape and fillet geometry,
wherein the processor (24) is configured to communicate with the database (26) and is programmed to process the images captured by the first (20) and second (22) cameras and to compute an aggregate probability that a weld posi-

tion corresponding to the images captured by the first and second cameras contains a defect based on the potential defects correlated in the database (26).

14. A system of claim 13, wherein the first camera (20) comprises two cameras including a leading edge camera that is positioned to capture images of the molten pool leading edge, and a trailing edge camera that is positioned to capture images of the molten pool trailing edge.

15. A system of claim 13, wherein the annular groove (12) is defined in a turbine rotor, wherein the weld metal is deposited in a plurality of overlapping passes by TIG torches (18) that fill the annular groove in the turbine rotor, and wherein a weld position is determined by a circumferential angle and a radial depth.

Patentansprüche

1. Verfahren zum Erkennen von Schweißfehlern in Echtzeit, wobei das Verfahren umfasst:

(a) Korrelieren potenzieller Schweißfehler mit Bildern eines Probeschweißschmelzbades für eine Probeschweißung und Bildern einer Schweißwellenform und Abrundungsgeometrie für eine Probeschweißung;
(b) Abscheiden von Schweißgut in eine Ringnut (12) bei einem Fertigungsschweißvorgang;
(c) eine erste Kamera (20), die Bilder eines Probeschweißschmelzbades für die Produktion während des Fertigungsschweißvorgangs aufnimmt;
(d) eine zweite Kamera (22), die Bilder einer Schweißwellenform und Abrundungsgeometrie einer Fertigungsschweißung während des Fertigungsschweißvorgangs aufnimmt; und
(e) Verarbeiten der in (c) und (d) aufgenommenen Bilder und Berechnen einer aggregierten Wahrscheinlichkeit, dass eine Schweißposition, die den in (c) und (d) aufgenommenen Bildern entspricht, einen Fehler enthält, basierend auf den potenziellen Fehlern, die in (a) korreliert sind.

2. Verfahren nach Anspruch 1, wobei Schritt (e) durch Analysieren einer Kantenform des Schmelzbades für die Fertigungsschweißung ausgeführt wird.

3. Verfahren nach Anspruch 1 oder 2, wobei Schritt (e) durch Analysieren einer Vorderkantenform des Schmelzbades für die Fertigungsschweißung und einer Hinterkantenform des Schmelzbades für die Fertigungsschweißung ausgeführt wird.

4. Verfahren nach einem der vorstehenden Ansprüche, **dadurch gekennzeichnet, dass** (a) das Korrelieren potenzieller Schweißfehler mit Bildern eines Probeschweißschmelzbades für eine Probeschweißung und Bildern einer Schweißwellenform und Abrundungsgeometrie für eine Probeschweißung Folgendes umfasst;

(a) Durchführen eines Probeschweißvorgangs in einer Lernphase, einschließlich

(1) Verwenden eines Schweißbrenners, Verschweißen eines ersten Teils (14) mit einem zweiten Teil (16),
(2) eine erste Kamera (20), die Bilder eines Schweißschmelzbades aufnimmt,
(3) eine zweite Kamera (22), die Bilder von einer Schweißwellenform und Abrundungsgeometrie aufnimmt,
(4) Korrelieren der in (2) und (3) aufgenommenen Bilder mit einer Schweißposition,
(5) Durchführen der Schweißprüfung an einer aus dem Verschweißen (1) resultierenden Schweißnaht und Charakterisieren von Fehlern in der Schweißnaht, und
(6) Korrelieren der charakterisierten Fehler mit Abweichungen in den in (2) und (3) aufgenommenen Bildern.

5. Verfahren nach Anspruch 1, ferner umfassend, nach Schritt (e) von Anspruch 1, das Ausgeben einer Warnung oder das Deaktivieren des Fertigungsschweißvorgangs basierend auf der aggregierten Wahrscheinlichkeit.

6. Verfahren nach Anspruch 4 oder Anspruch 5, wobei Schritt (a)(6) von Anspruch 4 durch Parametrisieren einer Form des Schweißschmelzbades und der Schweißwellenform und Abrundungsgeometrie durchgeführt wird.

7. Verfahren nach Anspruch 6, ferner umfassend, vor Schritt (a)(4) von Anspruch 4, das Aufnehmen von Bildern einer Form und Lage von feuerfesten Verunreinigungen im Schweißmodellbad, und wobei Schritt (a)(6) ferner das Parametrisieren der Form und Lage der feuerfesten Verunreinigungen umfasst.

8. Verfahren nach einem der vorstehenden Ansprüche 4 bis 7, ferner umfassend das Wiederholen der Schritte (a)(2)-(a)(6) von Anspruch 4 unter Verwendung der in (c) und (d) von Anspruch 1 erfassten Bilder.

9. Verfahren nach Anspruch 1, wobei der Fertigungsschweißvorgang durch Abscheiden von Schweißgut in einer Vielzahl von sich überlappenden Durchgängen durch WIG-Brenner durchgeführt wird, die eine Ringnut (12) in einem Turbinenrotor füllen, und wobei die Schweißposition durch einen Umfangswinkel und eine radiale Tiefe bestimmt wird.

10. Verfahren nach Anspruch 4, wobei Schritt (a)(5) von Anspruch 4 offline durch Ultraschallprüfung oder durch zerstörende Prüfung ausgeführt wird.

11. Verfahren nach Anspruch 4, wobei Schritt (a)(1) von Anspruch 4 ausgeführt wird, um den Schweißschritt bewusst außerhalb normaler Parameter durchzuführen, um künstliche Fehler zu erzeugen.

12. Verfahren nach Anspruch 4, wobei Schritt (a)(6) von Anspruch 4 durch Definieren von Schwellenwerten für Formabweichungen für das Schweißbad und die Schweißwellenform und Abrundungsgeometrie ausgeführt wird.

13. System zum Erkennen von Schweißfehlern in Echtzeit, wobei das System umfasst:

einen Schweißbrenner (18), der konfiguriert ist, um zu ermöglichen, dass Schweißgut in einer Ringnut (12) in einem Fertigungsschweißvorgang abgeschieden wird;
eine erste Kamera (20), die angrenzend an den Schweißbrenner und angrenzend an ein zu schweißendes Teil positioniert ist, wobei die erste Kamera konfiguriert ist, um Bilder eines Schmelzbades für die Fertigungsschweißnaht während des Fertigungsschweißvorgangs aufzunehmen;
eine zweite Kamera (22), die weiter von dem Schweißbrenner entfernt als die erste Kamera und stromabwärts vom Schweißbrenner positioniert ist, wobei die zweite Kamera konfiguriert ist, um Bilder einer Schweißwellenform und Abrundungsgeometrie einer Fertigungsschweißung während des Fertigungsschweißvorgangs aufzunehmen;
einen Prozessor (24), der konfiguriert ist, um die von der ersten und der zweiten Kamera aufgenommenen Bilder zu empfangen; und
eine Datenbank (26) mit darin gespeicherten korrelierten potenziellen Schweißfehlern mit Bildern eines Probeschweißschmelzbades für eine Probeschweißung und Bildern einer Schweißwellenform und Abrundungsgeometrie für eine Probeschweißung;
wobei der Prozessor (24) konfiguriert ist, um mit der Datenbank (26) zu kommunizieren, und programmiert ist, um die von der ersten (20) und der zweiten (22) Kamera aufgenommenen Bilder zu verarbeiten und basierend auf den in der Datenbank (26) korrelierten potenziellen Fehlern eine aggregierte Wahrscheinlichkeit zu berechnen, dass eine Schweißposition, die den von der ersten und der zweiten Kamera aufgenommenen Bildern entspricht, einen Fehler enthält.

14. System nach Anspruch 13, wobei die erste Kamera (20) zwei Kameras umfasst, die eine Vorderkantenkamera, die positioniert ist, um Bilder der Vorderkante des Schmelzbades aufzunehmen, und eine Hinterkantenkamera, die positioniert ist, um Bilder der Hinterkante des Schmelzbades aufzunehmen, einschließen.

15. System nach Anspruch 13, wobei die Ringnut (12) in einem Turbinenrotor definiert ist, wobei das Schweißgut in einer Vielzahl von sich überlappenden Durchgängen durch WIG-Brenner (18) abgeschieden wird, die die Ringnut in dem Turbinenrotor füllen, und wobei eine Schweißposition durch einen Umfangswinkel und eine radiale Tiefe bestimmt wird.

Revendications

1. Procédé de détection de défauts de soudure en temps réel, le procédé comprenant :

(a) la corrélation de défauts de soudure potentiels avec des images d'une simulation de bain de fusion de soudure et des images d'une simulation de forme d'ondulation de soudure et d'une géométrie des soudures d'angle ;
(b) le dépôt d'un métal de soudure dans une rainure annulaire (12) lors d'une opération de soudage de production ;
(c) une première caméra (20) capturant des images d'un bain de fusion de soudure de production pendant l'opération de soudage de production ;
(d) une seconde caméra (22) capturant des images d'une forme d'ondulation de soudage de production et d'une géométrie de soudure d'angle pendant l'opération de soudage de production ; et
(e) le traitement des images capturées en (c) et (d) et le calcul d'une probabilité globale qu'une position de soudage correspondant aux images capturées en (c) et (d) contienne un défaut sur la base des défauts potentiels corrélés en (a).

2. Procédé selon la revendication 1, dans lequel l'étape (e) est mise en œuvre en analysant une forme de bord du bain de fusion de soudure de production.

3. Procédé selon la revendication 1 ou 2, dans lequel l'étape (e) est mise en œuvre en analysant une forme de bord d'attaque du bain de fusion de soudure de production et une forme de bord de fuite du bain de fusion de soudure de production.

4. Procédé selon l'une quelconque des revendications précédentes, **caractérisé en ce que** (a) la corrélation des défauts de soudure potentiels avec des images d'une simulation de bain de fusion et des images d'une simulation de forme d'ondulation de soudure et d'une géométrie de soudures d'angle comprend en :

(a) la réalisation d'une opération de simulation de soudage dans une phase d'apprentissage incluant,

(1) l'utilisation d'une torche de soudage, en soudant une première partie (14) à une seconde partie (16),
(2) une première caméra (20) capturant des images d'un bain de fusion de soudage,
(3) une seconde caméra (22) capturant des images d'une forme d'ondulation de soudure et d'une géométrie d'angle,
(4) la corrélation des images capturées en (2) et (3) avec une position de soudage,
(5) la réalisation d'un test de soudure sur une soudure résultant du soudage en (1) et la caractérisation de tous les défauts dans la soudure, et
(6) la corrélation des défauts caractérisés avec des écarts dans les images capturées en (2) et (3).

5. Procédé selon la revendication 1, comprenant en outre, après l'étape (e) de la revendication 1, l'émission d'une alerte ou la désactivation de l'opération de soudage de production sur la base de la probabilité globale.

6. Procédé selon la revendication 4 ou la revendication 5, dans lequel l'étape (a) (6) de la revendication 4 est réalisée en paramétrant une forme du bain de fusion de soudure et la forme d'ondulation de soudure et la géométrie d'angle.

7. Procédé selon la revendication 6, comprenant en outre, avant l'étape (a) (4) de la revendication 4, la capture d'images d'une forme et d'un emplacement de contaminants réfractaires dans le groupe de câbles de soudure, et dans lequel l'étape (a) (6) comprend en outre le paramétrage de la forme et de l'emplacement des contaminants réfractaires.

8. Procédé selon l'une quelconque des revendications précédentes 4 à 7, comprenant en outre la répétition des étapes (a) (2) - (a) (6) selon la revendication 4 en utilisant les images capturées en (c) et (d) de la revendication 1.

9. Procédé selon la revendication 1, dans lequel l'opération de soudage de production est réalisée en déposant du métal de soudure en une pluralité de passages de recouvrement à l'aide de torches TIG qui remplissent une rainure annulaire (12) dans un rotor de turbine, et dans lequel la position de soudure est déterminée par un angle circonférentiel et une profondeur radiale.

10. Procédé selon la revendication 4, dans lequel l'étape (a) (5) de la revendication 4 est mise en œuvre hors ligne par un test aux ultrasons ou par des procédés de test destructif.

11. Procédé selon la revendication 4, dans lequel l'étape (a) (1) de la revendication 4 est mise en œuvre pour réaliser volontairement l'étape de soudage en dehors de paramètres normaux afin de créer artificiellement des défauts.

12. Procédé selon la revendication 4, dans lequel l'étape (a) (6) de la revendication 4 est mise en œuvre en définissant des seuils d'écarts de forme pour le bain de fusion de soudure et la forme d'ondulation de soudure et la géométrie d'angle.

13. Système de détection de défauts de soudure en temps réel, le système comprenant :

une torche de soudage (18) configurée pour permettre le dépôt d'un métal de soudure dans une rainure annulaire (12) lors d'une opération de soudage de production ;
une première caméra (20) positionnée de manière adjacente à la torche de soudage et adjacente à une pièce à souder, la première caméra étant configurée pour capturer des images d'un bain de fusion de soudure de production pendant l'opération de soudage de production ;
une seconde caméra (22) positionnée plus loin par rapport à la torche de soudage que la première caméra et en aval de la torche de soudage, la seconde caméra étant configurée pour capturer des images d'une forme d'ondulation de soudage de production et d'une géométrie d'angle pendant l'opération de soudage de production ;
un processeur (24) configuré pour recevoir les images capturées par les première et seconde caméras ; et
une base de données (26) dans laquelle sont stockés des défauts de soudure potentiels corrélés avec des images d'une simulation de bain de fusion de soudure et des images d'une simulation de forme d'onde de soudure et de géométrie d'angle,
dans lequel le processeur (24) est configuré pour communiquer avec la base de données

(26) et est programmé pour traiter les images capturées par les première (20) et seconde (22) caméras et pour calculer une probabilité globale qu'une position de soudage correspondant aux images capturées par les première et seconde caméras contienne un défaut sur la base des défauts potentiels corrélés dans la base de données (26).

14. Système selon la revendication 13, dans lequel la première caméra (20) comprend deux caméras incluant une caméra de bord d'attaque qui est positionnée de manière à capturer des images du bord d'attaque de bain de fusion, et une caméra de bord de fuite qui est positionnée de manière à capturer des images du bord de fuite du bain de fusion.

15. Système selon la revendication 13, dans lequel la rainure annulaire (12) est définie dans un rotor de turbine, dans lequel le métal de soudure est déposé en une pluralité de passages de recouvrement à l'aide de torches TIG (18) qui remplissent la rainure annulaire dans le rotor de turbine, et dans lequel une position de soudure est déterminée par un angle circonférentiel et une profondeur radiale.

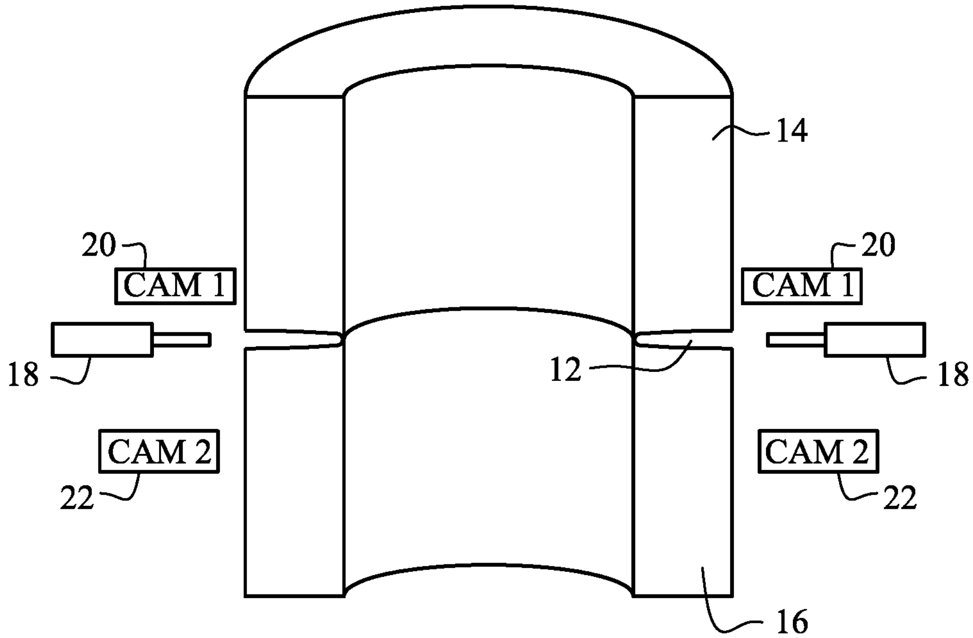
14
20
CAM 1
20
CAM 1
18
12
18
CAM 2
CAM 2
22
22
16

FIG. 1

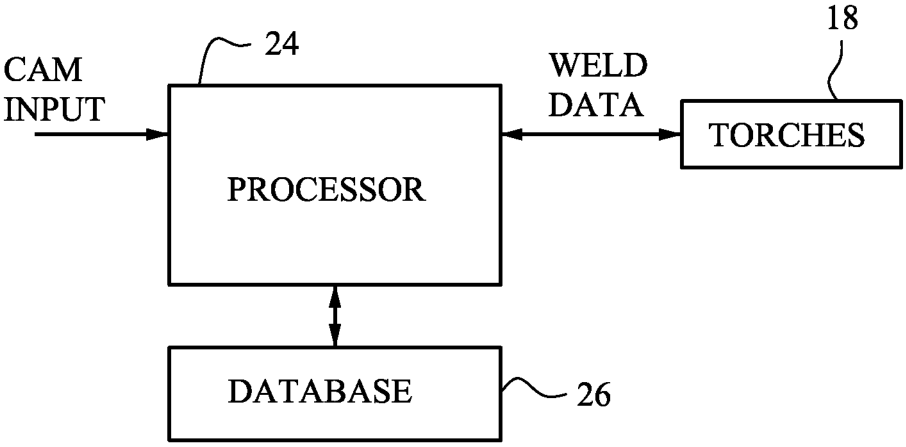
24
CAM
INPUT
PROCESSOR
WELD
DATA
18
TORCHES
DATABASE
26

FIG. 2

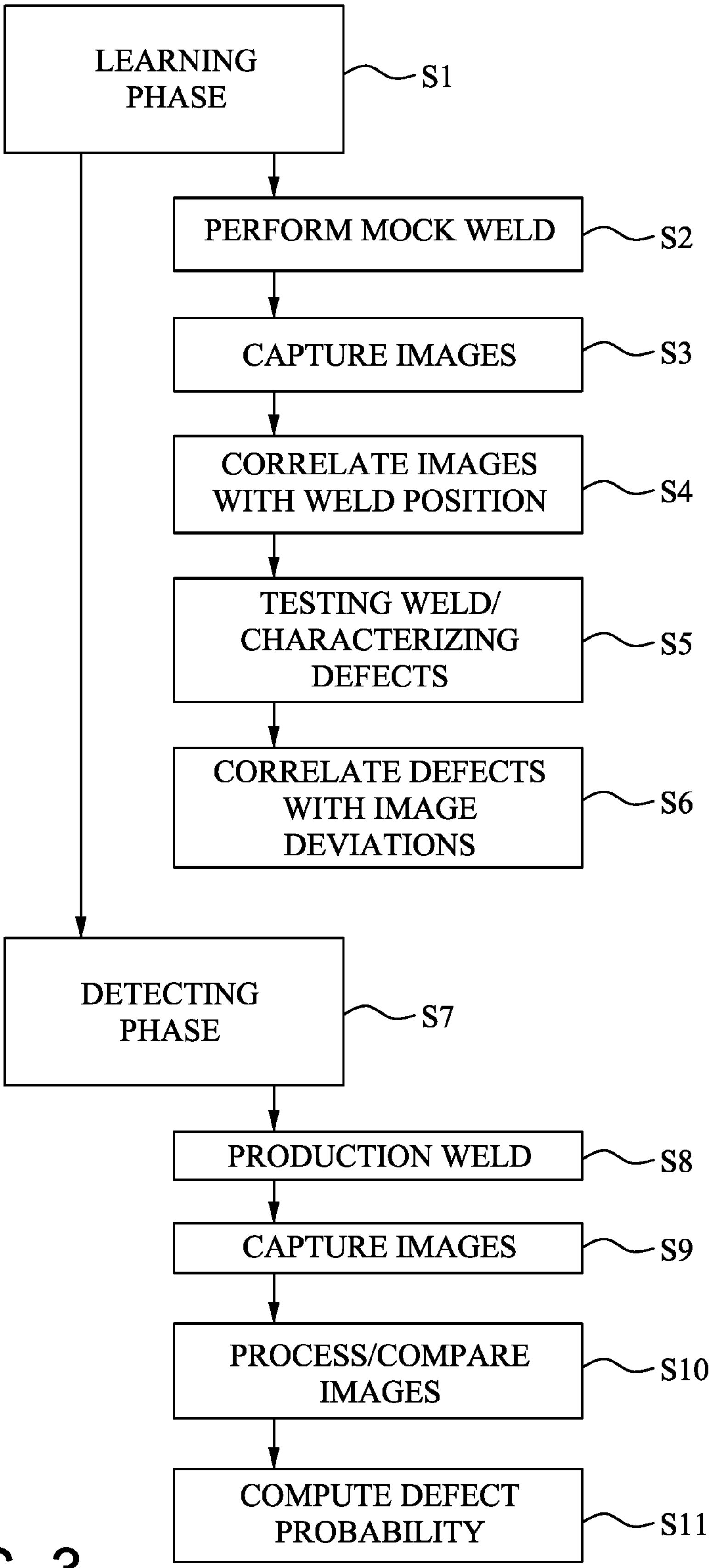
LEARNING PHASE
S1
PERFORM MOCK WELD
S2
CAPTURE IMAGES
S3
CORRELATE IMAGES WITH WELD POSITION
S4
TESTING WELD/ CHARACTERIZING DEFECTS
S5
CORRELATE DEFECTS WITH IMAGE DEVIATIONS
S6
DETECTING PHASE
S7
PRODUCTION WELD
S8
CAPTURE IMAGES
S9
PROCESS/COMPARE IMAGES
S10
COMPUTE DEFECT PROBABILITY
S11

FIG. 3

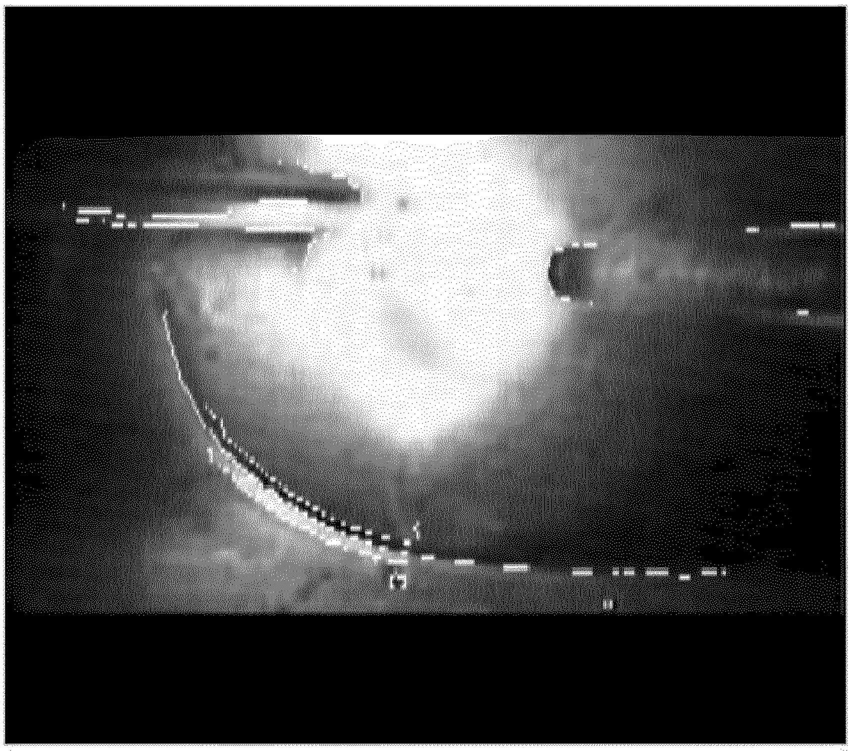

FIG. 4

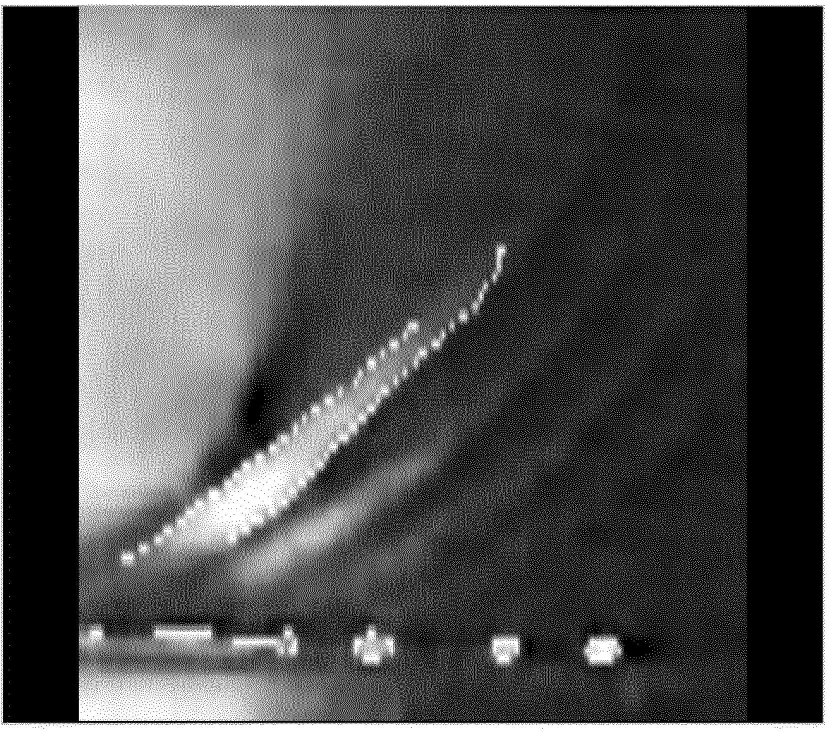

FIG. 5

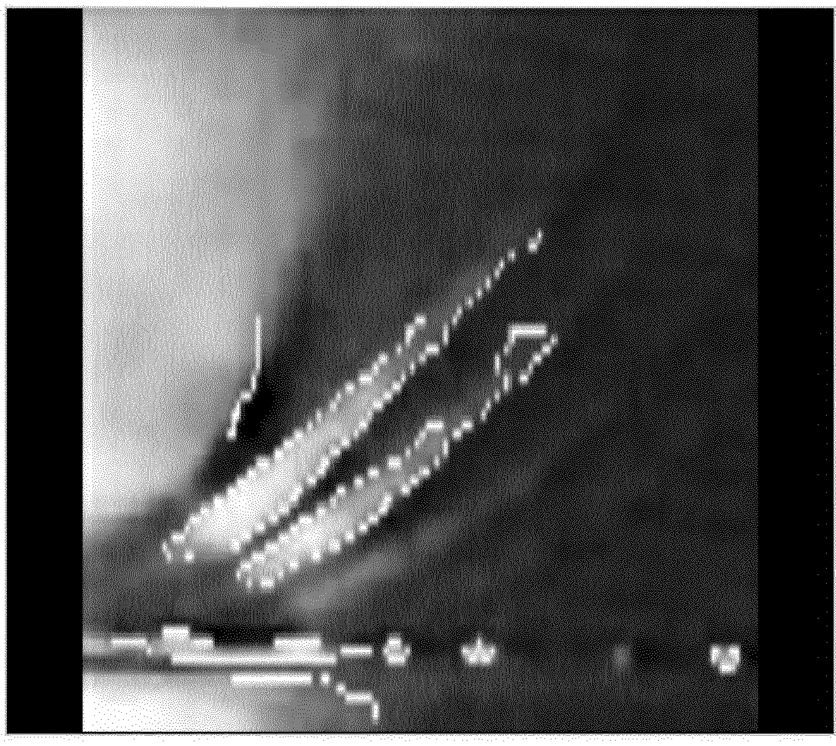

FIG. 6

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- US 20040124227 A1 **[0005]**
- JP 2009125790 A **[0006]**
- US 20150056585 A1 **[0007]**