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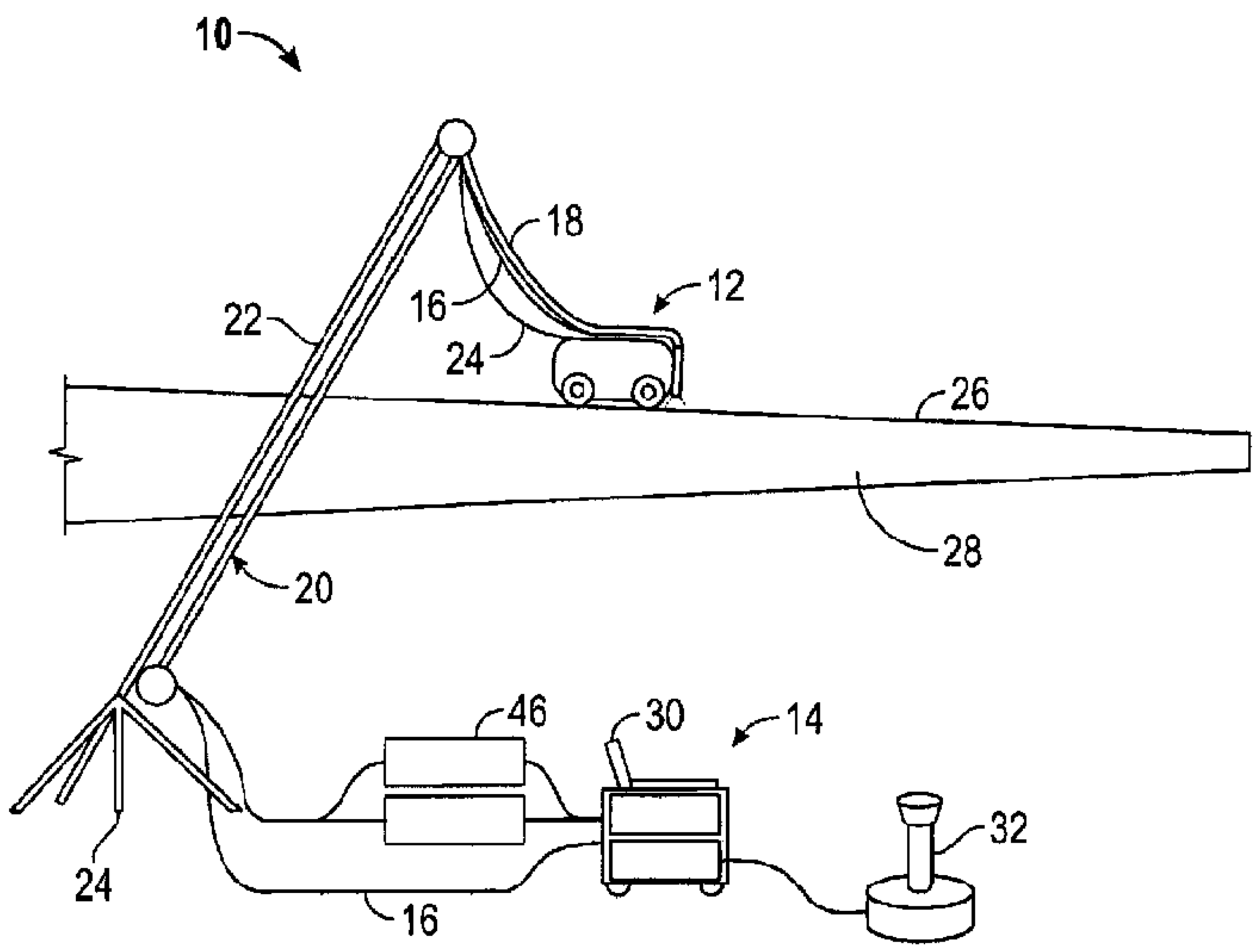

(57) Abrégé/Abstract:
A system for automated inspection of a surface; the system may include a self-propelled, steerable carriage capable of traversing the surface, the carriage having a camera positioned to view an object on the surface, and at least of one of a sensor capable of detecting a defect in the surface, a tool for treating the defect, and a sensor for inspecting a repair of the defect; and a computer controller connected to receive image data from the camera, communicate with and selectively actuate the at least of one of a sensor capable of detecting a defect in the surface, a tool for treating the defect, and a sensor for inspecting a repair of the defect, and control the carriage to move on the surface along one or more of a pre-set path and a path to one or more pre-set locations.

ABSTRACT

A system for automated inspection of a surface; the system may include a self-propelled, steerable carriage capable of traversing the surface, the carriage having a camera positioned to view an object on the surface, and at least of one of a sensor capable of detecting a defect in the surface, a tool for treating the defect, and a sensor for inspecting a repair of the defect; and a computer controller connected to receive image data from the camera, communicate with and selectively actuate the at least of one of a sensor capable of detecting a defect in the surface, a tool for treating the defect, and a sensor for inspecting a repair of the defect, and control the carriage to move on the surface along one or more of a pre-set path and a path to one or more pre-set locations.

SYSTEM AND METHOD FOR AUTOMATED CRACK INSPECTION AND REPAIR

FIELD

The disclosed system and method relate to inspection and repair of surface defects and, more particularly, to systems and methods for automated inspection and repair of cracks formed in a surface.

BACKGROUND

Inspection and repair of defects in a surface is often a costly and time-consuming procedure. For example, a single aircraft wing may include thousands of fasteners embedded in a carbon fiber panel. Each of the fasteners may be covered with a dielectric top to prevent lightning strikes from entering the fuel tank area. Each of the dielectric tops may be covered with a layer of paint.

Current inspection and repair is a completely manual operation. It is necessary to visually inspect each dielectric top to determine whether it is cracked. Cracks that are greater than **0**.**1** inches in length may require repair or replacement of the dielectric top. Once it is determined that a cracked dielectric top must be repaired, is necessary to manually remove the top, clean and prepare the exposed fastener surface, apply fresh dielectric material, and paint the material when hardened.

Such manual operations are time-consuming and costly. The completely manual nature of the operation may result in repair quality issues. The large amount of time required to inspect and repair dielectric tops on an aircraft in this manner may result in an aircraft being out of service for extended periods of time.

Accordingly, there is a need for a system and method for automating the inspection and repair of defects in a surface. Further, there is a need for automating the process of detection and repair of cracks and dielectric tops on the surfaces of aircraft wings.

SUMMARY

The disclosure describes a system for automated inspection and repair of a cracked dielectric top on a surface, the system including a first self-propelled, steerable carriage capable of traversing the surface. The first carriage includes: a camera positioned to view an object on the surface; at least one tool for treating the crack and including a dielectric top repair device; and at least one sensor including a crack detection sensor and a crack depth measurement sensor. The system further includes a computer controller configured to, at least: receive image data from the camera; communicate with and selectively actuate the at least one sensor; communicate with and selectively actuate the at least one tool to cause the at least one tool to treat the crack; control the first carriage to move on the surface; actuate the crack detection sensor to determine whether a crack exists in the dielectric top, and if the crack is detected and exceeds a predetermined minimal length, actuate the crack depth measurement sensor; and repair the crack by actuating the dielectric top repair device if the depth of the crack determined by the crack depth measurement sensor exceeds a predetermined depth.

The computer controller may be configured to control the first carriage to move on the surface along a pre-set path, a path to one or more pre-set locations, or both the pre-set path and the path to the one or more pre-set locations.

The computer controller may include a database containing at least one of the pre-set path, the path to the one or more pre-set locations, and a location of the crack, and the computer controller may control the first carriage to move on the surface along at least one of the pre-set path and the path to the one or more pre-set locations.

The surface may be a wing surface of an aircraft.

The surface may be a wing surface of an aircraft, and the one or more pre-set locations may include one or more locations of tops made of dielectric material covering fasteners in the wing surface.

The camera may be a high-definition camera.

The crack depth measurement sensor may utilize at least one of Fourier transform infrared (FTIR), Raman spectroscopy, ultraviolet fluorescence, laser fluorescence, and forced diffusion thermography to determine the depth of the crack.

The crack detection sensor may include one of high-resolution optical imaging with alternating light emitting diode (LED) side-lighting, a dye penetrant drop-and-wipe device including an ultraviolet lamp and chromatic dye deposition, ultraviolet or infrared laser fluorescence, and Raman spectroscopy.

The crack depth measurement sensor may include one of a terahertz measurement device for transmitting terahertz radiation to measure and/or image depth of the crack, a narrow beam laser adapted to scan the crack, and a forced diffusion thermography device for measuring an amount of heat transferred from one side of the crack to the other, the forced diffusion thermography device including a localized heat source to be positioned on one side of the crack and a mini uncooled infrared camera for imaging, a high frequency ultrasound generator adapted to direct one of an angled pitch-catch across the crack and a structural wave across the crack, a fiber optic laser ultrasound generator, a capacitance measurement sensor for measuring capacitance across the crack, a near-field millimeter wave generator, a mini x-ray backscatter device, a Fourier transform infrared (FTIR) generator, Raman spectroscopy utilizing a laser, and a laser for laser fluorescence.

The at least one sensor may include a sensor for inspecting the repair of the crack, and the computer controller may be configured to cause the sensor for inspecting the repair of the crack to inspect the repair of the crack.

The sensor for inspecting the repair of the crack may include one or more of a thermal imaging camera that utilizes infra-red thermography (IRT) to detect internal voids, a sensor using a microwave thickness gauge to determine whether a thickness of paint applied to the crack is sufficient, a sensor using an ultrasonic thickness gauge to determine whether the thickness of the paint applied to the crack is sufficient, a high-resolution camera for optical imaging to verify full coverage of dielectric material applied to the crack, a magneto-optical imaging device used as a full-field imaging method of mesh surrounding the crack, and an eddy current array.

The system may further include a second self-propelled, steerable carriage capable of traversing the surface, and the computer controller may be configured to communicate with and control movement of the second carriage.

The movement of the second carriage may be independent of the first carriage.

The movement of the second carriage may be coordinated with the first carriage.

The system may further include a stability mount for fixing the first carriage to the surface during operation of the at least one tool. The stability mount may communicate with the computer controller for selective activation and deactivation thereby.

The stability mount may be a suction device.

The at least one tool may be adapted to perform preparation of the cracked dielectric top for repair of the crack.

The at least one tool may be configured to apply at least one of acetone and methyl ethyl ketone (MEK).

The system may further include a tether rod connected to the first carriage and configured to provide fall arrest in the event that the first carriage falls from the surface.

The system may further include a cable connecting at least one of the camera, the at least one sensor, and the at least one tool to the computer controller. The cable may be supported at least partly by the tether rod.

The at least one tool may be capable of marking the cracked dielectric top for subsequent repair, and the computer controller may be configured to cause the at least one tool to mark the cracked dielectric top for subsequent repair.

The at least one tool may be capable of marking the cracked dielectric top for subsequent removal, and the computer controller may be configured to cause the at least one tool to mark the cracked dielectric top for subsequent removal.

The at least one tool may be capable of repairing the cracked dielectric top, and the computer controller may be configured to cause the at least one tool to repair the cracked dielectric top.

The at least one tool may be capable of removing the cracked dielectric top, and the computer controller may be configured to cause the at least one tool to remove the cracked dielectric top.

The at least one tool may include at least one of a rotating, semi-rigid plastic router adapted to remove dielectric tops from the surface, a pen marker, a sticker dispenser for marking dielectric tops for one of repair and removal, a dispenser of dielectric material, a dispenser of paint to cover dielectric material, and an appliqué dispenser configured to place an appliqué over dielectric material.

The computer controller may be configured to actuate the crack detection sensor to determine whether the crack exists in the dielectric top after visual inspection of the dielectric top with the camera.

The disclosure also describes method for automated inspection and repair of a cracked dielectric top on a surface. The method involves placing a self-propelled, steerable carriage on the surface, the carriage including: a camera positioned to view an object on the surface; at least one tool for treating the crack and including a dielectric top repair device; and at least one sensor including a crack detection sensor and a crack depth measurement sensor. The method further involves: receiving image data from the camera; communicating with and selectively actuating the at least one sensor; communicating with and selectively actuating the at least one tool to cause the at least one tool to treat the crack; controlling the carriage to move on the surface; actuating the crack detection sensor to determine whether a crack exists in the dielectric top, and if the crack is detected and exceeds a predetermined minimal length, actuating the crack depth measurement sensor; and repairing the crack by actuating the dielectric top repair device if the depth of the crack determined by the crack depth measurement sensor exceeds a predetermined depth.

Controlling the carriage to move on the surface may involve controlling the carriage to move on the surface along a pre-set path.

Controlling the carriage to move on the surface may involve controlling the carriage to move on the surface along a path to one or more pre-set locations.

Controlling the carriage to move on the surface to the one or more pre-set locations thereon may involve one or more of: accessing a table containing the one or more pre-set locations stored in a database; actuating the carriage to follow a metal foil grid on the surface interconnecting the one or more pre-set locations; and remotely steering the carriage on the surface using the camera.

Selectively actuating the at least one sensor and the at least one tool may involve selectively actuating at least one of: a rotating, semi-rigid plastic router adapted to remove the dielectric top from the surface; a pen marker and a sticker dispenser for marking

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the dielectric top for one of repair and removal; a dispenser for at least one of a dielectric material, a paint to cover dielectric material, and an appliqué configured to be placed over the dielectric material; a computer control to record a location of the crack in a database; a suction device for fixing the carriage to the surface; a crack depth sensor utilizing at least one of Fourier transform infrared, Raman spectroscopy, ultraviolet fluorescence, laser fluorescence, and forced diffusion thermography to determine a depth of the crack; an applicator to apply at least one of acetone and methyl ethyl ketone (MEK) to prepare the surface for repair of the crack; a thermal imaging camera that utilizes infra-red thermography (IRT) to detect internal voids; a sensor using a microwave thickness gauge to determine whether a thickness of paint applied to the crack is sufficient; a sensor using an ultrasonic thickness gauge to determine whether the thickness of the paint applied to the crack is sufficient; a high-resolution camera for optical imaging to verify full coverage of dielectric material applied to the crack; a magneto-optical imaging device used as a full-field imaging method of mesh surrounding the crack; and an eddy current array.

The surface may be a wing surface of an aircraft.

The cracked dielectric top may include dielectric material covering a fastener in the surface.

Actuating the crack detection sensor to determine whether the crack exists in the dielectric top may involve actuating the crack detection sensor to determine whether the crack exists in the dielectric top after visual inspection of the dielectric top with the camera.

The method may further involve inspecting the repair of the crack by actuating a sensor capable of inspecting the repair of the crack.

These and other features and functions of the disclosed method and system will be apparent from the following description, the accompanying drawings and the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. **1** is a somewhat schematic, side elevation of the described system for automated crack inspection and repair; and

Fig. **2** is a detail showing the carriage of the system shown in Fig. **1**.

DETAILED DESCRIPTION

As shown in Fig. **1**, the system for automated crack inspection and repair, generally designated **10**, may include a carriage, generally designated **12**, that is in communication with a computer controller, generally designated **14**. The carriage **12** may communicate with the computer controller **14** by wireless communication, such as using the Bluetooth communication protocol, or as shown, using a data communication cable **16** that extends between the computer controller and the carriage. A power cable **18** also may extend between and link the carriage **12** with the computer controller **14**.

The system **10** may also include a boom or tether rod **20**. The tether rod **20** may consist of an elongate shaft **22** made of a rigid material, such as polyvinyl chloride (PVC) or fiberglass, and may include a stand **24** that rests upon the ground. The tether rod **20** also may convey and support the cables **16**, **18** that interconnect the carriage **12** with the computer control **14**, and may include a support cable **24** for fall arrest; namely, to protect the carriage **12** in the event it inadvertently falls from a surface.

As shown in Fig. **1**, the carriage **12** may be placed upon a surface, which in an embodiment may be the upper surface **26** of an aircraft wing **28**. The upper surface **26** may be oriented substantially horizontally, so that the carriage may be guided by the computer control **14** in a pre-set, horizontal path along the upper surface.

The computer control **14** may include a visual display **30**, and optionally may include a carriage steering device or controller **32** for manual guidance of the carriage **12**.

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As shown in Fig. **2**, the carriage **12** may be a self-propelled, steerable carriage that includes a chassis, generally designated **34**, that may include wheel pairs **36, 38** (four wheels in all) of which wheel pair **36** and/or wheel pair **38** may be steerable by powered steering linkage **40** actuated by computer control **14**. Wheels pairs **36**, **38** may be driven by an onboard electric motor or motors **42**, and may include friction material to prevent slippage on surface **26**. The powered steering linkage **40** and motors **42** may be actuated, powered and controlled by the computer control **14** (Fig. **1**) through the cables **16, 18**.

The carriage **12** also may include a high-resolution camera **44** mounted on the chassis **34**. The high-resolution camera **44** may be connected to the computer controller **14** through cable **16** (Fig. **1**) and may be configured so view and transmit a high resolution-image of the surface **26**, and objects on the surface, which in embodiments may include surface features, markings on or embedded in the surface, or dielectric tops covering fasteners, to the computer control **14** and shown on display **30**. Further, computer control **14** may include data storage **46** containing image analysis software for processing images of the surface **26** and objects on the surface transmitted from the camera **44**. In embodiments, the camera **44** may be fixed relative to chassis **34**, or be mounted for pivotal movement relative thereto, the pivotal movement being remotely actuated by computer controller **14** or manually through computer controller **32**.

In embodiments, data storage **46** may include one or more pre-set paths and/or a table of one or more pre-set locations, which in embodiments may be inspection and/or repair paths and inspection and/or repair locations, identified on a specified surface **26** of a particular model aircraft. Thus, the computer control may actuate the carriage to travel on the surface **26** along one or more of a pre-set path and a path to one or more pre-set locations on the surface.

The carriage **12** also may include a sensor capable of detecting a defect in the surface **26**, which in an embodiment may be crack depth sensor **48** mounted on the chassis **34** and connected to the computer control **14** by cable **16**, or wirelessly. The crack depth sensor **48** may include instrumentation for finding a defect in the surface **26**, which in an embodiment may include a crack in a top **50** made of dielectric material that covers a fastener **52** in the aircraft wing **28**. The sensor **48** may include high-resolution optical imaging with alternating light emitting diode (LED) side-lighting to show up a crack in a dielectric top **50** in any orientation. In other embodiments, the sensor **48** may include a dye penetrant drop-and-wipe device that utilizes ultraviolet light to detect a crack, in which the sensor **48** may include an ultraviolet lamp configured to direct ultraviolet light on the dielectric top and imaging is made of the lighted area using paint with chromatic dyes deposited on the area by the sensor **48**. In other embodiments, the sensor **48** may utilize ultraviolet or infrared laser fluorescence, by fluorescing materials in the dielectric top, or by using Raman spectroscopy, or by other known methods and devices.

In an embodiment, the carriage **12** may include a crack depth measurement sensor **54**, mounted on the chassis **34** and connected to the computer control **14** by cable **16**, or wirelessly. Crack depth measurement sensor **54** may be employed to measure the depth of a crack detected in the dielectric top **50**. The crack depth measurement sensor **54** may include a terahertz measurement device that transmits terahertz radiation upon the dielectric top **50** to measure and/or image the depth of a crack in the dielectric top. In other embodiments, the crack depth measurement sensor **54** may include a narrow beam laser that is scanned over the crack in the dielectric top **50**, and the time-of-flight difference between the surface and the bottom of the crack may be measured to determine the depth of the crack. In another embodiment, the crack depth measurement sensor **54** may include a forced diffusion thermography device that measures the amount of heat transferred from one side of the crack in the dielectric top **50** to the other, and include a localized heat source applied to one side of the crack and the dielectric top is imaged with a mini uncooled infrared camera included in the crack depth measurement sensor **54**.

In still other embodiments, the crack depth measurement sensor **54** may utilize a high frequency ultrasound generator. The ultrasound projector may direct an angled pitch-catch across the crack or structural wave across the crack. In other embodiments, the crack depth measurement sensor **54** may include a fiber optic laser ultrasound generator. In other embodiments, the crack depth measurement sensor **54** may include one or more of capacitance measurement across the crack in the dielectric top **50**, a near-field millimeter wave generator, a mini x-ray backscatter device, a Fourier transform infrared (FTIR) generator, Raman spectroscopy utilizing a laser, and/or laser fluorescence (fluorescing at **792** nm). If the crack in the dielectric top **50** exceeds a predetermined depth, the dielectric top **50** either may be marked for later repair or may be repaired by a tool for treating the defect, such as a device **56** mounted on the carriage chassis **34**.

In an embodiment, the chassis **34** may include a tool for treating a defect in the surface **26**, which in an embodiment may include device **56**, actuated and powered by computer controller **14**, to mark cracked dielectric tops for subsequent repair or removal. In an embodiment, the device **56** may include a pen marker using an actuator to mark the dielectric top **50** with ink. In other embodiments, the device **56** may include a dispenser that dispenses stickers or appliqué, and in other embodiments, the device **56** may include a digital marker that transmits a signal through the cable **16** to the computer control **14** (Fig. **1**) that records the location (either by an assigned number or by coordinates) of the cracked dielectric top **50** on the wing **28** on a database **46**. The digital marker may include local positioning system (LPS) software or motion capture software to determine the location of the dielectric top **50**.

In other embodiments, the tool for treating a defect in the surface **26** may include device **56** being adapted to function as a dielectric top repair device, actuated and powered by computer controller **14**. In such embodiments, the device **56** may include a device for removing a dielectric top, which may include a dielectric material remover that may be in the form of a plastic router powered through cable **18** from the computer controller **14**. In other embodiments, the device **56** may consist of or include a dispenser of acetone or methyl ethyl ketone (MEK) and chemical auto-wipe with a green residue recovery system. Such a dispenser would prepare the surface beneath the cracked dielectric top **50** (i.e., the top surface of the fastener **52**) for application of a replacement dielectric top.

In embodiments, the device **56** may include a dispenser that deposits dielectric material over the fastener **52** and/or applies paint over the reapplied dielectric material. In yet other embodiments, the device **56** may apply an appliqué over the dielectric material **50** instead of paint. The dielectric material dispenser and appliqué dispenser **56** also may be connected to be actuated and powered by computer controller **14**.

In such embodiments in which device **56** may include a dielectric top repair device, the carriage **12** may be configured such that one of the sensors **48**, **54** may be a sensor for inspecting a repair of a defect in the surface **26**, which in an embodiment may include a sensor for verifying the integrity of a repair made by device **56**. In such embodiments, sensor **54**, for example, may be a thermal imaging camera that utilizes infra-red thermography (IRT) to detect internal voids in the replacement dielectric top **50** applied to the fastener **52**. In other embodiments, sensor **48** may be a microwave or ultrasonic thickness gauge to measure the thickness of paint applied to the top of the fastener **52**. In such embodiments, optical imaging with the high-resolution camera **44** may verify full coverage of the dielectric.

In other embodiments, an electromagnetic method may be used, such as a capacitive method for checking the material filler capacitance, or eddy current to check for the mesh around the edge of the fastener **52**. In such an embodiment, sensor **48** may be a magneto-optical imaging device, which may be used as a full-field imaging method of the surrounding mesh (like eddy current but providing a **2**-D image), or the sensor **48**, **54** may be an eddy current array.

In embodiments, the carriage **12** may include a stability mount **58** that is selectively actuated by the computer controller **14** (Fig. **1**). The stability mount **58** may, in some embodiments, include a suction device in the form of one or more suction cups to provide a vacuum assist for stabilizing and fixing the carriage **12** during an inspection or repair operation. The stability mount **58** may be powered by and selectively activated by computer controller **14**.

In embodiments, the system **10** may include one or more than one carriage **12**. In embodiments comprising multiple carriages **12**, each carriage may be configured to perform a different function, such as a different one of inspection, marking, repair and repair inspection. In embodiments comprising multiple carriages **12**, the computer controller **14** may operate carriages **12** in conjunction with each other, in which, for example, a first carriage **12** performs crack detection, and a second carriage performs crack marking and or repair. In other embodiments, the second carriage **12** may be operated by the computer controller **14** to operate independently of the first carriage **12**, in which, for example, both first and second carriages **12** may perform the same aforementioned function or functions, or different ones of the aforementioned functions.

In embodiments, the system **10** may be configured such that the computer control **14** guides the carriage **12** over a pre-set pattern of locations from one fastener **52** to another fastener on the aircraft wing **28**, in which the computer controller guides the carriage **12** along a path from one pre-set location of a fastener **52** on the wing to another pre-set location of a fastener **52**. Data comprising path and fastener locations for thc wing **28** of a particular aircraft may be stored in storage **46** as part of computer controller **14**, or called by computer controller from a remote location over a network (not shown). In other embodiments, the carriage **12** may follow a copper foil grid **60** mounted on or embedded in the surface **26** of the aircraft wing **28** that interconnects the fasteners **52**. In embodiments, the carriage **34** may be guided to one or more pre-set locations (i.e., from one fastener location to another) manually by a user using controller **32**, entirely by the computer control **14**, or a combination of both manually and by computer control.

The operation of the system **10** for automated crack inspection and repair is as follows. The carriage **12** may be placed upon the surface **26** of an aircraft wing **28**, either manually or by a robot arm (not shown). In embodiments, the carriage **12** may be placed upon other surfaces of an aircraft or other vehicle. One or more of the specific type of aircraft wing **28**, the pattern of fasteners **50** on that wing and the path to be traveled by the carriage **12** may be stored locally in database **46** of computer control **14** or accessed from a remote location. The carriage **12** initially may be guided by a user using controller **32** to an initial location, which may be a preselected fastener **52** and dielectric top **50**. The high resolution camera **44** may be actuated and utilized at this time for proper location of the carriage **12** relative to progressing to and centering over the fastener **52** and dielectric top **50**. In embodiments, the carriage **12** simply may include a sensor (e.g., sensor **54**) configured to follow the copper grid **60** to thc appropriate initial location.

The dielectric top **50** may be visually inspected through the high resolution camera **44** at this time. Alternately, or in addition, the crack detection sensor **48** may be actuated by the computer control **14**. The crack detection sensor **48** may utilize one or more of the aforementioned crack detection methods to determine whether a crack exists in the dielectric top **50**. If a crack is detected and exceeds a predetermined minimal length, such as **0**.**1** inches, the computer control **14**, or a human operator at the computer control, may actuate the crack depth measurement sensor **54**. Alternately, the crack depth measurement sensor **54** may be on a second carriage **12** that follows a first carriage. The crack depth measurement sensor **54** may utilize one or more of the aforementioned methods for measuring the depth of the crack in the dielectric top **50**.

If the depth of the crack exceeds a predetermined depth, a decision may be made to repair the crack or mark the crack for repair at a later time, or by a second, following carriage **12**. If it is decided to mark the crack, a stability mount **58** may be actuated to fix the carriage **34** in place on the surface **26** relative to the crack in the dielectric top **50**. A tool in the form of device **56** may be actuated by the computer control **14** to employ one or more of the aforementioned methods to mark the crack with a pen, apply a sticker using a dispenser, or utilize digital marking by recording the location of the cracked dielectric top **50** in a database at **46**, or in a remote database.

Alternately, or in addition, the device **56** may be actuated to repair the crack. This may involve actuating a dielectric material remover utilizing one or more of the aforementioned methods, such as by a plastic router. The device **56** also may include a chemical auto wipe device that applies acetone or MEK with a green residue recovery system. The carriage **12** may be repositioned so that the camera **44** inspects the excavated fastener head cavity that has been cleaned, and the cavity shown on display **30** to be viewed by a user. It may be necessary at this time to verify that all material has been removed from the cavity previously filled by the now-removed dielectric material, and that the surface of the fastener and the surface of the aircraft wing **26** is clean.

The device **56** may be actuated to reapply dielectric material, repaint over the applied dielectric material, or in the alternative apply an appliqué over the dielectric material instead of paint. After this replacement process has been completed, the high-resolution camera **44** may transmit an image of the completed repair to the display **30** so that a human operator may determine whether the quality of the repair is acceptable. In embodiments, the carriage **12** may include one or more sensors **48** to inspect the repair, as by using IRT to detect internal voids, and/or microwave or ultrasonic thickness gauges to determine whether the thickness of the paint is sufficient. After repairing the dielectric top **50**, the computer control **14** may actuate the carriage **12** to move to a next successive dielectric top **50** location on the aircraft wing surface. This process may be repeated for each of the dielectric tops on the surface **26** of an aircraft wing **28**. In embodiments, the carriage **34** may include an inspection device **56** that uses a capacitance check to verify electromagnetic event ("EME") protection.

The foregoing system **10** and method provides a consistent, repeatable and accurate inspection method that identifies cracks in dielectric tops on a surface before they become an issue. The method is extremely valuable from a cost, as well as a safety standpoint. Further, the disclosed method and system extends the time required between inspections relative to a method that is limited to detecting larger cracks, such as a simple visual method that relies on human eyes alone. A more significant cost avoidance may be provided by the described system and method as a result of the automation and speed of inspection. The crawling carriage **12** may reduce significantly the man hours and manpower required to perform a dielectric top inspection over the surface **26** of an aircraft wing **28** that may include thousands of dielectric tops **50**.

While specific embodiments of the invention have been described and illustrated, such embodiments should be considered illustrative of the invention only and not as limiting the invention as construed in accordance with the accompanying claims.

EMBODIMENTS IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. A system for automated inspection and repair of a cracked dielectric top on a surface, the system comprising:

a first self-propelled, steerable carriage capable of traversing the surface and comprising:

a camera positioned to view an object on the surface;

at least one tool for treating the crack and comprising a dielectric top repair device; and

at least one sensor comprising a crack detection sensor and a crack depth measurement sensor; and

a computer controller configured to, at least:

receive image data from the camera;

communicate with and selectively actuate the at least one sensor;

communicate with and selectively actuate the at least one tool to cause the at least one tool to treat the crack;

control the first carriage to move on the surface;

actuate the crack detection sensor to determine whether a crack exists in the dielectric top, and if the crack is detected and exceeds a predetermined minimal length, actuate the crack depth measurement sensor; and repair the crack by actuating the dielectric top repair device if the depth of the crack determined by the crack depth measurement sensor exceeds a predetermined depth.

2. The system of claim **1** wherein the computer controller is configured to control the first carriage to move on the surface along a pre-set path, a path to one or more pre-set locations, or both the pre-set path and the path to the one or more pre-set locations.

3. The system of claim **2**, wherein the computer controller includes a database containing at least one of the pre-set path, the path to the one or more pre-set locations, and a location of the crack, and the computer controller controls the first carriage to move on the surface along at least one of the pre-set path and the path to the one or more pre-set locations.

4. The system of claim **1**, **2** or **3**, wherein the surface is a wing surface of an aircraft.

5. The system of claim **2** or **3**, wherein the surface is a wing surface of an aircraft, and the one or more pre-set locations include one or more locations of tops made of dielectric material covering fasteners in the wing surface.

6. The system of any one of claims **1** to **5**, wherein the camera is a high-definition camera.

7. The system of any one of claims **1** to **6**, wherein the crack depth measurement sensor utilizes at least one of Fourier transform infrared (FTIR), Raman spectroscopy, ultraviolet fluorescence, laser fluorescence, and forced diffusion thermography to determine the depth of the crack.

8. The system of any one of claims **1** to **7**, wherein the crack detection sensor includes one of high-resolution optical imaging with alternating light emitting diode (LED) side-lighting, a dye penetrant drop-and-wipe device including an ultraviolet lamp and chromatic dye deposition, ultraviolet or infrared laser fluorescence, and Raman spectroscopy.

9. The system of any one of claims **1** to **8**, wherein the crack depth measurement sensor includes one of a terahertz measurement device for transmitting terahertz radiation to measure and/or image depth of the crack, a narrow beam laser adapted to scan the crack, and a forced diffusion thermography device for measuring an amount of heat transferred from one side of the crack to the other, the forced diffusion thermography device including a localized heat source to be positioned on one side of the crack and a mini uncooled infrared camera for imaging, a high frequency ultrasound generator adapted to direct one of an angled pitch-catch across the crack and a structural wave across the crack, a fiber optic laser ultrasound generator, a capacitance measurement sensor for measuring capacitance across the crack, a near-field millimeter wave generator, a mini x-ray backscatter device, a Fourier transform infrared (FTIR) generator, Raman spectroscopy utilizing a laser, and a laser for laser fluorescence.

10. The system of any one of claims **1** to **9**, wherein the at least one sensor comprises a sensor for inspecting the repair of the crack, and wherein the computer controller is configured to cause the sensor for inspecting the repair of the crack to inspect the repair of the crack.

11. The system of claim **10** wherein the sensor for inspecting the repair of the crack includes one or more of a thermal imaging camera that utilizes infra-red thermography (IRT) to detect internal voids, a sensor using a microwave thickness gauge to determine whether a thickness of paint applied to the crack is sufficient, a sensor using an ultrasonic thickness gauge to determine whether the thickness of the paint applied to the crack is sufficient, a high-resolution camera for optical imaging to verify full coverage of dielectric material applied to the crack, a magneto-optical imaging device used as a full-field imaging method of mesh surrounding the crack, and an eddy current array.

12. The system of any one of claims **1** to **11**, further comprising:

a second self-propelled, steerable carriage capable of traversing the surface;

wherein the computer controller is configured to communicate with and control movement of the second carriage.

13. The system of claim **12**, wherein the movement of the second carriage is independent of the first carriage.

14. The system of claim **12**, wherein the movement of the second carriage is coordinated with the first carriage.

15. The system of any one of claims **1** to **14**, further comprising a stability mount for fixing the first carriage to the surface during operation of the at least one tool, the stability mount communicating with the computer controller for selective activation and deactivation thereby.

16. The system of claim **15**, wherein the stability mount is a suction device.

17. The system of any one of claims **1** to **16**, wherein the at least one tool is adapted to perform preparation of the cracked dielectric top for repair of the crack.

18. The system of claim **17**, wherein the at least one tool is configured to apply at least one of acetone and methyl ethyl ketone (MEK).

19. The system of any one of claims **1** to **18**, further comprising a tether rod connected to the first carriage and configured to provide fall arrest in the event that the first carriage falls from the surface.

20. The system of claim **19**, further comprising a cable connecting at least one of the camera, the at least one sensor, and the at least one tool to the computer controller, the cable being supported at least partly by the tether rod.

21. The system of any one of claims **1** to **20**, wherein the at least one tool is capable of marking the cracked dielectric top for subsequent repair, and wherein the computer controller is configured to cause the at least one tool to mark the cracked dielectric top for subsequent repair.

22. The system of any one of claims **1** to **21**, wherein the at least one tool is capable of marking the cracked dielectric top for subsequent removal, and wherein the computer controller is configured to cause the at least one tool to mark the cracked dielectric top for subsequent removal.

23. The system of any one of claims **1** to **22**, wherein the at least one tool is capable of repairing the cracked dielectric top, and wherein the computer controller is configured to cause the at least one tool to repair the cracked dielectric top.

24. The system of any one of claims **1** to **23**, wherein the at least one tool is capable of removing the cracked dielectric top, and wherein the computer controller is configured to cause the at least one tool to remove the cracked dielectric top.

25. The system of any one of claims **1** to **24**, wherein the at least one tool includes at least one of: a rotating, semi-rigid plastic router adapted to remove dielectric tops from the surface; a pen marker; a sticker dispenser for marking dielectric tops for one of repair and removal; a dispenser of dielectric material; a dispenser of paint to cover dielectric material; and an appliqué dispenser configured to place an appliqué over dielectric material.

26. The system of any one of claims **1** to **25**, wherein the computer controller is configured to actuate the crack detection sensor to determine whether the crack exists in the dielectric top after visual inspection of the dielectric top with the camera.

27. A method for automated inspection and repair of a cracked dielectric top on a surface, the method comprising:

placing a self-propelled, steerable carriage on the surface, the carriage comprising:

a camera positioned to view an object on the surface;

at least one tool for treating the crack and comprising a dielectric top repair device; and

at least one sensor comprising a crack detection sensor and a crack depth measurement sensor;

receiving image data from the camera;

communicating with and selectively actuating the at least one sensor;

communicating with and selectively actuating the at least one tool to cause the at least one tool to treat the crack;

controlling the carriage to move on the surface;

actuating the crack detection sensor to determine whether a crack exists in the dielectric top, and if the crack is detected and exceeds a predetermined minimal length, actuating the crack depth measurement sensor; and

repairing the crack by actuating the dielectric top repair device if the depth of the crack determined by the crack depth measurement sensor exceeds a predetermined depth.

28. The method of claim 27, wherein controlling the carriage to move on the surface comprises controlling the carriage to move on the surface along a pre-set path.

29. The method of claim **27** or **28**, wherein controlling the carriage to move on the surface comprises controlling the carriage to move on the surface along a path to one or more pre-set locations.

30. The method of claim **29**, wherein controlling the carriage to move on the surface to the one or more pre-set locations thereon includes one or more of:

accessing a table containing the one or more pre-set locations stored in a database;

actuating the carriage to follow a metal foil grid on the surface interconnecting the one or more pre-set locations; and

remotely steering the carriage on the surface using the camera.

31. The method of claim **27**, **28**, **29**, or **30**, wherein selectively actuating the at least one sensor and the at least one tool includes selectively actuating at least one of:

a rotating, semi-rigid plastic router adapted to remove the dielectric top from the surface;

a pen marker and a sticker dispenser for marking the dielectric top for one of repair and removal;

a dispenser for at least one of a dielectric material, a paint to cover dielectric material, and an appliqué configured to be placed over the dielectric material;

a computer control to record a location of the crack in a database;

a suction device for fixing the carriage to the surface;

a crack depth sensor utilizing at least one of Fourier transform infrared, Raman spectroscopy, ultraviolet fluorescence, laser fluorescence, and forced diffusion thermography to determine a depth of the crack;

an applicator to apply at least one of acetone and methyl ethyl ketone (MEK) to prepare the surface for repair of the crack;

a thermal imaging camera that utilizes infra-red thermography (IRT) to detect internal voids;

a sensor using a microwave thickness gauge to determine whether a thickness of paint applied to the crack is sufficient;

a sensor using an ultrasonic thickness gauge to determine whether the thickness of the paint applied to the crack is sufficient;

a high-resolution camera for optical imaging to verify full coverage of dielectric material applied to the crack;

a magneto-optical imaging device used as a full-field imaging method of mesh surrounding the crack; and

an eddy current array.

32. The method of any one of claims **27** to **31**, wherein the surface is a wing surface of an aircraft.

33. The method of any one of claims **27** to **32**, wherein the cracked dielectric top comprises dielectric material covering a fastener in the surface.

34. The method of any one of claims **27** to **33**, wherein actuating the crack detection sensor to determine whether the crack exists in the dielectric top comprises actuating the crack detection sensor to determine whether the crack exists in the dielectric top after visual inspection of the dielectric top with the camera.

35. The method of any one of claims **27** to **34**, further comprising inspecting the repair of the crack by actuating a sensor capable of inspecting the repair of the crack.

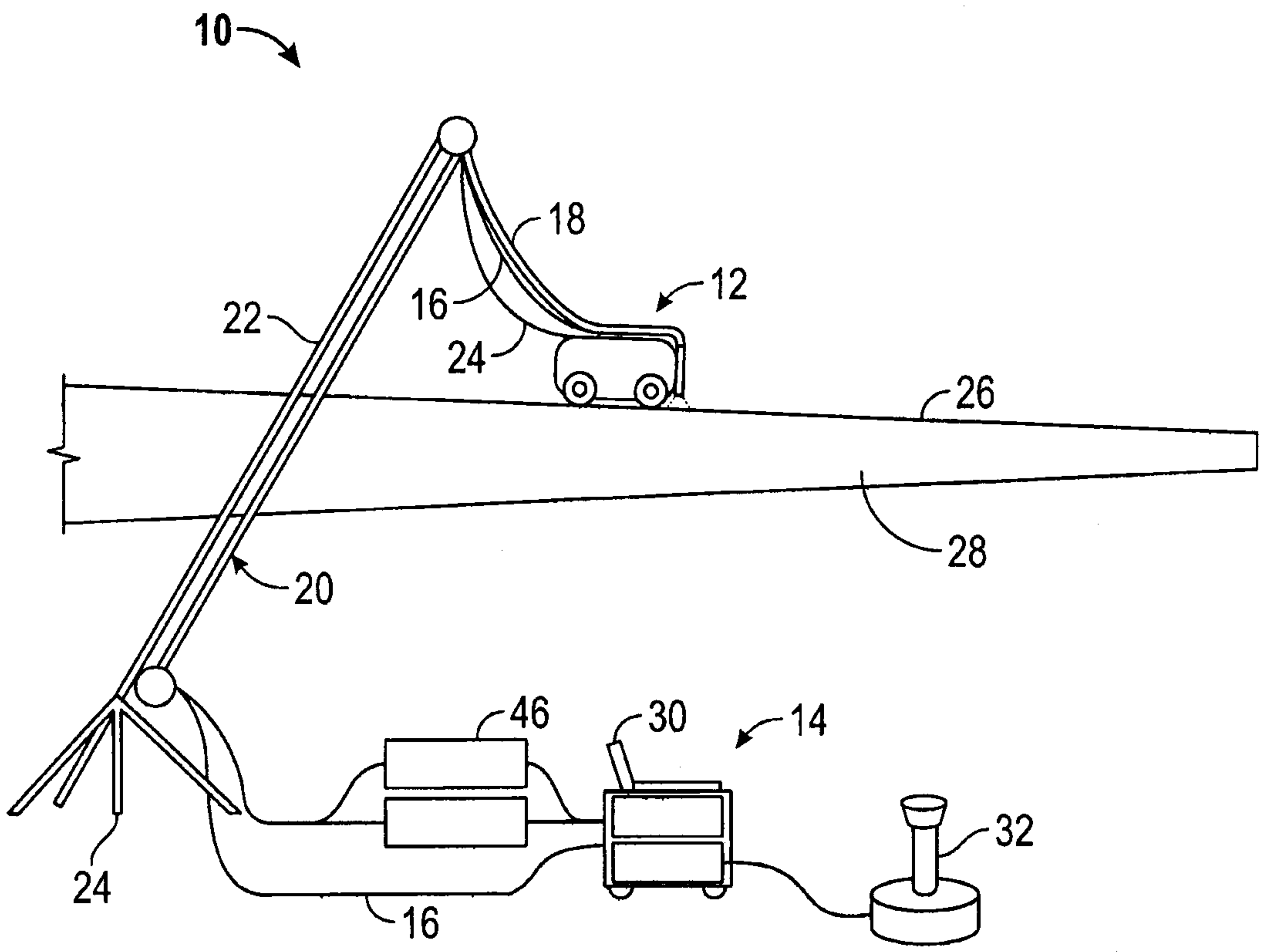


FIG. 1

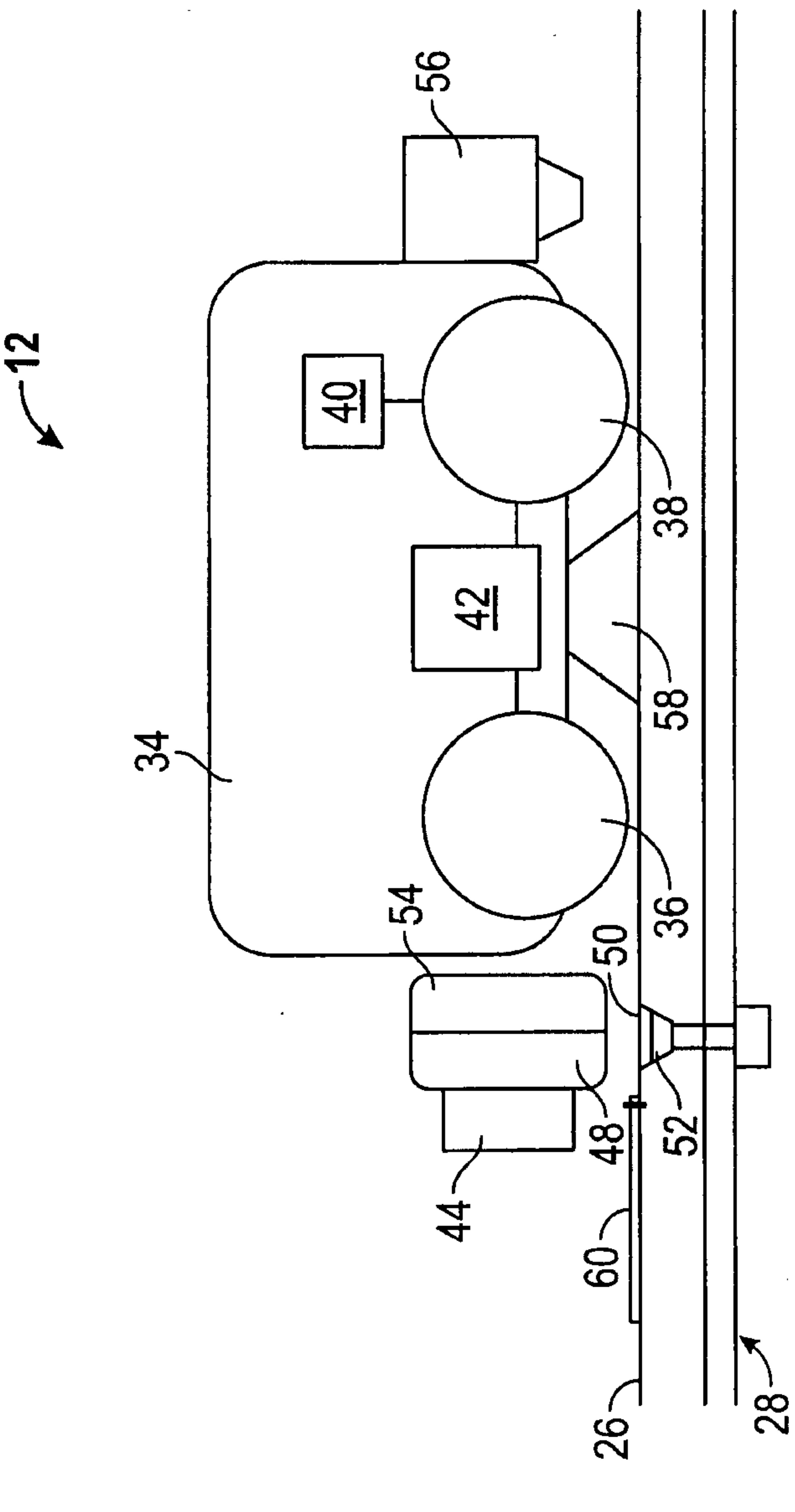
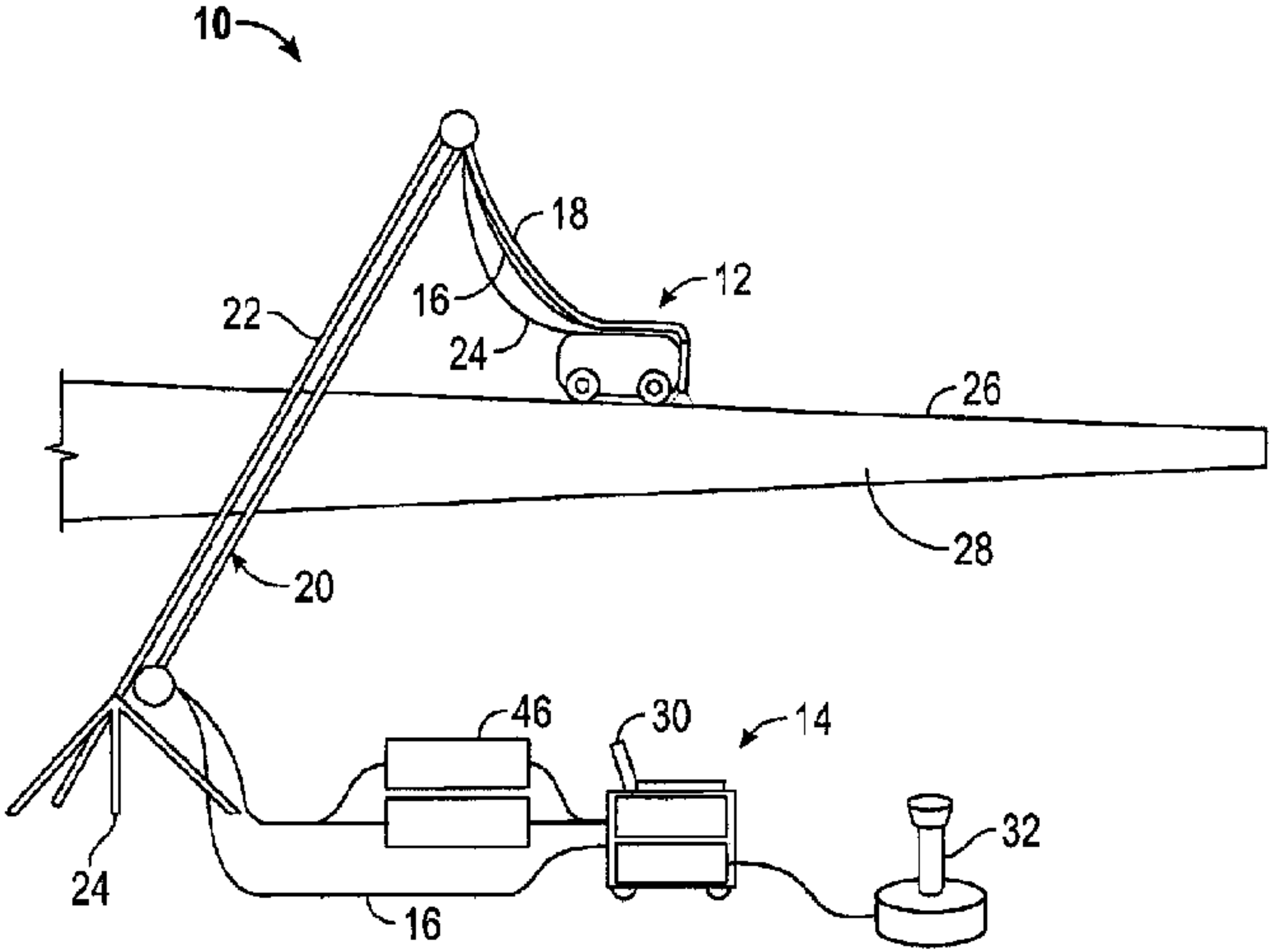


FIG. 2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