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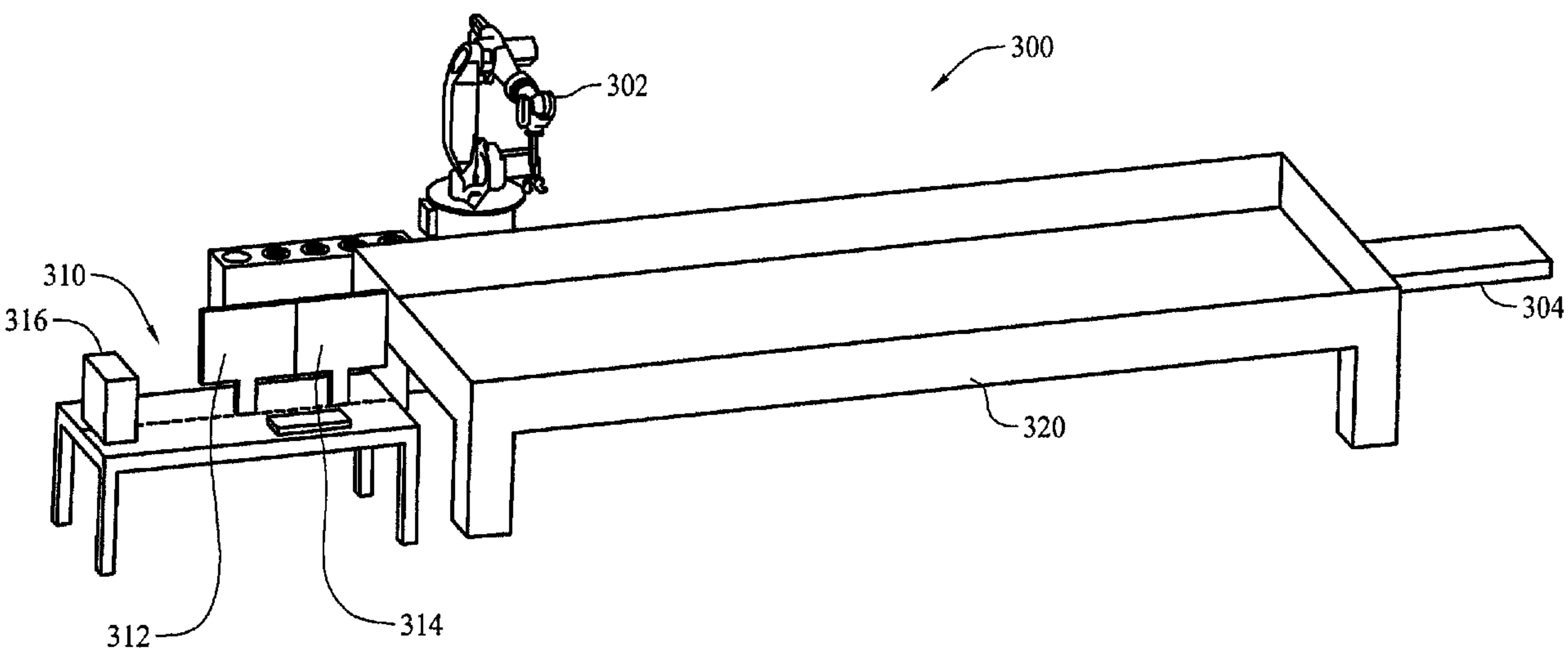
(54) **Titre :** SYSTEMES ET METHODES D'ESSAI NON DESTRUCTIF AVEC SONDES INTERCHANGEABLES
(54) **Title:** NON-DESTRUCTIVE INSPECTION SYSTEMS AND METHODS THAT INCORPORATE INTERCHANGEABLE PROBES



(57) **Abrégé/Abstract:**
A non-destructive inspection (NDI) device is described that includes a robotic arm, a storage device proximate the robotic arm, and a plurality of NDI probe assemblies disposed within the storage device. Each NDI probe assembly includes at least one transducer operable for NDI of a part and a tool operable as a mechanical interface between the robotic arm and the corresponding NDI probe assembly. Each NDI probe assembly is configured for a specific NDI task, for NDI of a part, and the robotic arm is operable for selectively engaging the tools and movement of the probe assemblies for the NDI of at least a portion of a part.

NON-DESTRUCTIVE INSPECTION SYSTEMS AND METHODS THAT INCORPORATE INTERCHANGEABLE PROBES

ABSTRACT OF THE DISCLOSURE

A non-destructive inspection (NDI) device is described that includes a robotic arm, a storage device proximate the robotic arm, and a plurality of NDI probe assemblies disposed within the storage device. Each NDI probe assembly includes at least one transducer operable for NDI of a part and a tool operable as a mechanical interface between the robotic arm and the corresponding NDI probe assembly. Each NDI probe assembly is configured for a specific NDI task, for NDI of a part, and the robotic arm is operable for selectively engaging the tools and movement of the probe assemblies for the NDI of at least a portion of a part.

NON-DESTRUCTIVE INSPECTION SYSTEMS AND METHODS THAT INCORPORATE INTERCHANGEABLE PROBES

BACKGROUND

The field of the disclosure relates generally to non-destructive inspection (NDI) equipment and processes, and more particularly to NDI systems and methods that incorporate interchangeable probes.

Part of the fabrication process for composite parts, for example, primary structural composite parts and composite rib parts for an aircraft, includes a non-destructive inspection (NDI) process. However, in one example fabrication, the composite ribs are not identical to one another. That is, rib number two is a completely different size, for example, than rib number five. Further in this example fabrication, ribs destined for the right side of the aircraft are different from the ribs destined for the left side of the aircraft.

Currently, NDI is performed using an x-y-z scanner with NDI probes attached to an end of the effector. The NDI probes are interchanged by an operator to perform the various NDI tests associated with a part. Separate inspection systems for individual components, and operator interchanging of probes, is cost prohibitive. Further, as much NDI is performed in deep water tanks, the expense associated with such tanks is a cost that companies would like to avoid.

Robotic inspection with ultrasonic NDI systems has always had limitations due to the sensitivity of the probe heads to electrical connection/disconnection. As described above, however, having a different probe head for every inspection condition would result in a heavy and complex end effector that would impact the size and cost of the robot.

BRIEF DESCRIPTION

In one aspect, a non-destructive inspection (NDI) device is provided that includes a robotic arm, a storage device proximate the robotic arm, and a plurality of NDI probe assemblies disposed within the storage device. Each NDI probe assembly includes at least one transducer operable for NDI of a part and a tool operable as a mechanical interface between the robotic arm and the corresponding NDI probe assembly. Each NDI probe assembly is configured for a specific NDI task, for NDI of a part, and the robotic arm is operable for selectively engaging the tools and movement of the probe assemblies for the NDI of at least a portion of a part.

The disclosure describes a method for non-destructive inspection (NDI) of a part that incorporates multiple structural features. The method involves selecting an NDI probe assembly from a plurality of NDI probe assemblies held in a probe storage device proximate the robotic arm, the selection based upon one or more of the multiple structural features associated with the part to be inspected, engaging the selected NDI probe assembly with the robotic arm and moving the robotic arm from the probe storage device to an inspection area to engage the selected NDI probe assembly with the part to be inspected, proximate one of the structural features of the part that is associated with the selected NDI probe assembly. The method also involves guiding the NDI probe assembly along the part in a defined path while a transducer associated with the selected NDI probe assembly provides and receives signals associated with NDI, returning the selected NDI probe assembly to the probe storage device and repeating the selecting, engaging, moving, guiding, and returning steps for at least one more NDI probe assembly, each NDI probe assembly associated with at least one different structural feature of the part and communicatively coupled to a corresponding electronic assembly both when the NDI probe assembly is deployed on the robotic arm and when the NDI probe assembly is in the storage device.

The disclosure also describes a non-destructive inspection (NDI) system including a linear track including a carriage operable to move along the linear track, a robotic arm mounted to the carriage and a storage device mounted to the carriage. The system also includes a plurality of electronic assemblies mounted to the carriage, each of the electronic assemblies operable to provide signals for the operation of specific transducers utilized in NDI and a plurality of NDI probe assemblies disposed within the storage device communicatively coupled to a corresponding electrical assembly, each NDI probe assembly including at least one transducer operable for NDI of a component and a mechanical interface to the robotic arm, for NDI of a component having a plurality of structural features. The system is programmed to operate the robotic arm to select, engage and remove one of the NDI probe assemblies from the storage device for NDI of at least one specific structural feature and place the removed NDI probe assembly in a position with respect to the component that causes the at least one transducer associated with the NDI probe assembly to be proximate a start position for NDI of the at least one structural feature. The system is also programmed to execute a command to start the NDI, move the removed NDI probe assembly along at least one defined scan path using at least one of the carriage and the robotic arm and return the removed NDI probe assembly to the storage device upon completion of the NDI of the structural features of the component associated with the removed NDI assembly. The system is further programmed to repeat the operation, placement, execution, movement and returning for each of the NDI probe assemblies within the storage device needed to complete a specific set of NDI tests for a plurality of structural features associated with the component.

The disclosure also describes a system for non-destructive inspection (NDI) of a part that incorporates multiple structural features. The system also includes a robotic arm, provisions proximate the robotic arm, for storing a plurality of NDI probe assemblies associated with at least one different structural feature of the part and provisions for selecting an NDI probe assembly from the plurality of NDI probe assemblies held in the provisions for storing, the selection based upon one or more of the multiple structural features associated with the part to be inspected. The system also includes provisions for engaging the selected NDI probe assembly with the robotic arm and provisions for communicatively coupling each NDI probe assembly to a corresponding electronic assembly both when the NDI probe assembly is engaged with the robotic arm and when the NDI probe assembly is in the storage provisions. The system also includes provisions for moving the robotic arm from the storing provisions to an inspection area to engage the selected NDI probe assembly with the part to be inspected, proximate one of the structural features of the part that is associated with the selected NDI probe assembly and provisions for guiding the NDI probe assembly along the part in a defined path while a transducer associated with the selected NDI probe assembly provides and receives signals associated with NDI. The system also includes provisions for returning the selected NDI probe assembly to the provisions for storing and provisions for causing the selecting, engaging, moving, guiding, and returning steps to be repeated for at least one more of the NDI probe assemblies.

The features, functions, and advantages that have been discussed can be achieved independently in various embodiments or may be combined in yet other embodiments further details of which can be seen with reference to the following description and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure **1** is a flow diagram of an aircraft production and service methodology.

Figure **2** is a block diagram of an aircraft.

Figure **3** is a front view depiction of a non-destructive inspection (NDI) system according to one embodiment.

Figure **4** is a rear view depiction of the NDI system of Figure **3**.

Figure **5** is a flowchart illustrating robotic motion control program actions for the NDI of a part using the system of Figures **3** and **4**.

Figure **6** includes plots of upper radius and cap data for hat stiffeners.

Figure **7** includes plots of lower radius and side data for hat stiffeners.

Figure **8** includes plots of inner radius data for hat stiffeners.

Figure **9**A illustrates composite data from NDI transducers in the form of amplitude data.

Figure **9**B illustrates composite data from NDI transducers in the form of time of flight data.

Figure **10** is an image of amplitude data as stitched together by the system of Figures **3** and **4**.

Figure **11** is a block diagram of one embodiment of an ultrasonic subsystem interface for the system of Figures **3** and **4**.

Figure **12** is a view of a probe assembly.

Figure **13** is a view of an upper radius and cap probe assembly.

Figure **14** is an alternate view of the upper radius and cap probe assembly of Figure **13**.

Figure **15** is a view of a lower radius and side probe holder assembly.

Figure **16** is an alternate view of the lower radius and side probe holder assembly of Figure **15**.

Figure **17** illustrates an inner radius probe holder assembly.

Figure **18** is a diagram of a data processing system.

DETAILED DESCRIPTION

The described embodiments are directed to a non-destructive inspection (NDI) system that performs NDI of multiple ribs and stringers for an aircraft, though the embodiments should not be construed to be so limited. The described embodiments perform the NDI in a shallow water tank, which is more cost efficient than deep water tank NDI testing.

In an embodiment, the NDI system incorporates a robotic arm and multiple NDI probe assemblies that can be interchanged on the robotic arm which allows for implementation of NDI of composite ribs of different design. More specifically, the programming associated with operation of the robotic arm and the multiple NDI probe assemblies yield good data scans and provides efficient NDI scans for multiple rib configurations. Further, the described NDI system embodiments are (estimated >5X) faster and more reliable than NDI systems currently utilized to inspect similar structures. The NDI process is automated by the embodiments described herein, allowing for a reduction in the number of NDI operators.

To accomplish the above mentioned improvements, the NDI system incorporates multiple NDI probes assemblies for inspection of the various structural features of the various composite parts. Such probe assemblies are incorporated into an automated system for NDI. The NDI system further incorporates a robotic arm that facilitates NDI probe selection, positioning and scanning. The usage of multiple NDI probe assemblies with a single robotic arm device results in reduced cost as multiple NDI systems and/or robotic systems for the probe scanning of the various composite structural parts are not needed.

In one embodiment, technical effects of the methods, systems, and computer-readable media described herein include at least one of: (a) providing a lean and efficient non-destructive inspection system and method for a complex composite part, (b) selecting an NDI probe assembly from a plurality of NDI probe assemblies staged proximate a robotic arm, the selection based upon one or more of the multiple structural features associated with the part to be inspected, (c) engaging the selected NDI probe assembly with the robotic arm, (d) moving the robotic arm from the staging area to an inspection area such that the selected NDI probe assembly engages the part to be inspected proximate one of the structural features of the part that is associated with the selected NDI probe assembly, (e) guiding the NDI probe assembly along the part in a defined path while a transducer associated with the selected NDI probe assembly provides and receives signals associated with NDI, (f) returning the selected NDI probe assembly to the staging area, and (g) repeating the selecting, engaging, moving guiding, and returning steps for at least one more NDI probe assembly staged proximate the robotic arm, each NDI probe assembly associated with at least one different structural feature of the part.

As used herein, an element or step recited in the singular and proceeded with the word "a" or "an" should be understood as not excluding plural elements or steps unless such exclusion is explicitly recited. Furthermore, references to "one embodiment" of the present invention or the "exemplary embodiment" are not intended to be interpreted as excluding the existence of additional embodiments that also incorporate the recited features.

Referring more particularly to the drawings, embodiments of the disclosure may be described in the context of aircraft manufacturing and service method **100** as shown in Figure **1** and an aircraft **200** as shown in Figure **2**. During pre-production, aircraft manufacturing and service method **100** may include specification and design **102** of aircraft **200** and material procurement **104**.

During production, component and subassembly manufacturing **106** and system integration **108** of aircraft **200** takes place. Thereafter, aircraft **200** may go through certification and delivery **110** in order to be placed in service **112**. While in service by a customer, aircraft **200** is scheduled for routine maintenance and service **114** (which may also include modification, reconfiguration, refurbishment, and so on).

Each of the processes of aircraft manufacturing and service method **100** may be performed or carried out by a system integrator, a third party, and/or an operator (e.g., a customer). For the purposes of this description, a system integrator may include, without limitation, any number of aircraft manufacturers and major-system subcontractors; a third party may include, for example, without limitation, any number of venders, subcontractors, and suppliers; and an operator may be an airline, leasing company, military entity, service organization, and so on.

As shown in Figure **2**, aircraft **200** produced by aircraft manufacturing and service method **100** may include airframe **202** with a plurality of systems **204** and interior **206**. Examples of systems **204** include one or more of propulsion system **208**, electrical system **210**, hydraulic system **212**, and environmental system **214**. Any number of other systems may be included in this example. Although an aerospace example is shown, the principles of the disclosure may be applied to other industries, such as the automotive industry.

Apparatus and methods embodied herein may be employed during any one or more of the stages of aircraft manufacturing and service method **100**. For example, without limitation, components or subassemblies corresponding to component and subassembly manufacturing **106** may be fabricated or manufactured in a manner similar to components or subassemblies produced while aircraft **200** is in service.

Also, one or more apparatus embodiments, method embodiments, or a combination thereof may be utilized during component and subassembly manufacturing **106** and system integration **108**, for example, without limitation, by substantially expediting assembly of or reducing the cost of aircraft **200**. Similarly, one or more of apparatus embodiments, method embodiments, or a combination thereof may be utilized while aircraft **200** is in service, for example, without limitation, to maintenance and service **114** may be used during system integration **108** and/or maintenance and service **114** to determine whether parts may be connected and/or mated to each other.

The description of the different advantageous embodiments has been presented for purposes of illustration and description, and is not intended to be exhaustive or limited to the embodiments in the form disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art. Further, different advantageous embodiments may provide different advantages as compared to other advantageous embodiments. The embodiment or embodiments selected are chosen and described in order to best explain the principles of the embodiments, the practical application, and to enable others of ordinary skill in the art to understand the disclosure for various embodiments with various modifications as are suited to the particular use contemplated.

Turning now to Figure **3**, a diagram of a non-destructive inspection (NDI) system **300** is depicted in accordance with an illustrative embodiment. The system **300** shall consist of multiple data acquisition, ultrasonic electronic and robotic mechanical scan sub-systems in combination with corresponding probes and probe holders as well as a part immersion tank arranged as shown in Figures **3** and **4**. More specifically, NDI system **300** includes a six-axis joint-arm (pedestal) robot **302** movable along a linear rail **304**. In the configuration of Figure **3**, incorporation of the linear unit **304** in combination with robot **302** provides a total of seven axes of coordinated motion. As shown in Figure **3**, NDI system **300** includes an operator interface **310** that includes, for example, displays **312, 314** and processing device **316**. A shallow water tank **320** is utilized for immersion of the components to be subjected to the NDI tests. As can be understood from Figure **3**, movement of robot **302** along rail **304**, and the six axis movement of robot **302** allows for an inspection probe **330** to be moved to any location within shallow water tank **320**.

Robot **302** further incorporates an ultrasonic probe assembly changer capability as better seen in the rear view of Figure **4**. Referring to Figure **4**, a probe storage device **400** includes a master side plate **402** that is attached to a face plate **410** of the robot **302**. Probe storage device **400** is configured for storage of a plurality of probe assemblies as further described below.

A linear axis carriage **430** provides space for an equipment rack **440** containing electronic units **442** that correspond to the specific ultrasonic units within the individual probe assemblies **450** disposed within probe storage device **400**. To address the issues described herein with the connecting, disconnecting, and reconnecting of probe assemblies **450** to their respective supporting electronics units **442**, a series of cables **460** are incorporated into NDI system **300** that allow for the semi-permanent attachment between the electronic units **442** and respective NDI probe assemblies **450**. In use, the cables **460** are routed and maintained in positions that allow for the robot **302** to extract, utilize, and replace an individual probe assembly **450** with respect to probe storage device **400** while maintaining the electrical interconnection between the electronic units **442** and respective NDI probe assemblies **450**. One of cables **460** is shown in Figure **460** as being connected to an NDI probe assembly **450** that is deployed on the robot **302**.

In an embodiment, each probe assembly **450** consists of one or more ultrasonic inspection probes, the associated probe holder and a tool that provides a mechanical interface between the robot **302** and the probe assembly **450**. In the NDI of a lower inside radius of an aircraft stringer, for example, multiple NDI probe assemblies **450** may be utilized. In one NDI probe assembly **450**, for example, an outside magnetic guidance fixture is provided as well as a holder for the ultrasonic transducers. The outside guidance fixture is configured for the mechanical placement of the corresponding transducer(s) in specific locations with respect to a component being inspected by system **300**. Specifically, the outside magnetic guidance fixture is operable, via the robotic arm **302** to engage a component **470** upon which an NDI is to be performed. As such, the multiple probe assemblies **450** correspond to and incorporate the various mechanical features necessary to place the various transducers in positions that allow for the complete NDI of a component or part.

Cables connecting the ultrasonic inspection probes (e.g., pulser-receiver units) and the corresponding electronic units **442** are deployed within a cable track sufficient to enable all required electrical interconnects between the linear unit of robot **302** and the fixed equipment stand of operator interface **310**. As an example, a cable track generally contains a **110** volt AC power line, and an Ethernet data transfer cable.

Operation of NDI system **300** requires an operator to enter the working space of the robot **302**. In one embodiment, a railing system and light screen based robot guarding system is incorporated into NDI system **300** that deactivates the power to the robot **302** when the operator enters the work space.

NDI system **300** utilizes a robotic motion control program that can be converted into executable scan programs by adding point coordinates using a teach pendant. The basic motion control program is designed to start at a safe "home" position, select an NDI probe assembly **450**, do a series of approximately straight line scans, return the NDI probe assembly **450**, and return to home. In embodiments, the home position is different for each of the parts that are tested with the NDI system **300**. This is necessary so since the scanning of the parts with NDI system **300** requires a different program be executed to inspect each of the parts. Also, each of the probes will require a different scanning program due to the mechanical configuration differences. In embodiments of the scanning programs, safety features are linked into the scanning software to prevent collisions between the probe and robot combination and one or more of the part being inspected, the tooling fixtures, and the shallow water tank **320**.

Figure **5** is a flowchart **500** illustrating robotic motion control program actions for the NDI of a part, in this example a rib, using the system **300** described herein. The robot **302** is programmed to start by moving **502** the effector end to a home position. An NDI probe assembly **450** is selected **504**, based on the relevant portion of the part that is to be inspected. Selection of the NDI probe assembly **450** includes moving the arm of the robot **302** to the location where the relevant NDI probe assembly can be extracted from probe storage device **400**. Based on the program being executed, the extracted NDI probe assembly **450** is moved **506** to starting point P**1**a of scan **1**. As understood, there is an interpolation between a position of the robot, its arm, and the transducer of the probe assembly **450** that is attached to the robot.

The scan is started **508** as the system **300** issues a TTL scan start pulse and begins output of position pulses. The scan is executed **508**, for example, by moving the effector end (the transducer within the probe) in a straight line from point P1a to end point P1b. Generally, movement is approximately along an axis. As the effector end reaches end point P1b, output of position pulses is terminated **512** and a TTL scan stop pulse is issued. The end effector is moved upwards to a clearance position, generally along a positive Z axis, and if the scan is not complete **514**, the probe assembly, and therefore the transducer, are moved **516** to the starting position of the next scan, for example, start point P**2**a of scan **2**. The remaining scans are executed, as shown in flowchart **500** until all scans associated with the particular NDI probe assembly **450** are complete **514**, at which point the NDI probe assembly **450** is returned **518** to probe storage device **400**, and the robot arm is returned to the home position.

In one embodiment, and relevant to a specific set of composite components to be inspected, ultrasonic data is generated, with the various probe assemblies **450**, in the following order with start scan and end of scan pulses for each data segment: N segments of upper radius and cap data for hat stiffeners **1** through N, N segments of lower radius and side data for hat stiffeners **1** through N, N segments of inner radius data for hat stiffeners **1** through N, M segments of web data for the composite rib, and stitched scans of the web.

The data acquisition software operating in one embodiment of system **300** displays the data arranged as follows: N segments each containing aligned upper radius and cap, lower radius and side, and inner radius data. More particularly, the data is displayed as shown in Figures **6** through **8**, where Figure **6** includes plots **600** of upper radius and cap data for hat stiffeners, Figure **7** includes plots **700** of lower radius and side data for hat stiffeners, and Figure **8** includes plots **800** of inner radius data for hat stiffeners. Plots **600**, **700**, and **800** have the stringer data shown individually per transducer shoe. For NDI analysis process flow, it is desired to have the data files stitched together and displayed in one image per rib.

The data after it has been acquired for all the probes for a stringer shall display the data as a composite image. Figures **9**A and **9**B have both the amplitude and time of flight images for the data files per ultrasonic gate as Figures **9**A and **9**B include plots **900** and **910** respectively illustrate composite data from the transducers in the form of amplitude data and time of flight data.

In one embodiment, the NDI data scans for the composite rib are stitched together into one image where amplitude and time of flight data are displayed. Figure **10** is an image **1000** of the amplitude data as stitched together by system **300**.

Figure **11** is a block diagram of one embodiment of a ultrasonic subsystem interface **1100** for system **300**. In the illustrated embodiment, subsystem interface **1100**, which is sometimes referred to as an electronic pulser-receiver system, includes three linear transducer units **1102**, **1104**, **1106** that are coupled to the computer **316**, also providing encoder signals to robot **302**. In a specific embodiment, transducer units **1102**, **1104**, and **1106** are Olympus NDT Focus linear transducer units, though NDI systems could also be utilized in addition or in combination with those shown in Figure **11**. As shown in Figure **11**, transducer unit **1102** is coupled to an interface box **1112**, which provides an interface between transducer unit **1102** and the transducers therein, particularly an upper radius cap shoe transducer element **1122** and a low inside radius shoe transducer element **1124**. Transducer unit **1104** is coupled to an interface box **1114**, which provides an interface between transducer unit **1104** and the transducers therein, particularly a low outside radius and stringer side shoe transducer element **1132**. Transducer unit **1106** is directly coupled to a web shoe transducer **1140**.

Figure **12** is a view of a probe assembly **450**. In operation, a probe holder **1200** is attached to the robot **302**. The robot **302** is programmed to engage the appropriate probe assembly **450** such that it is extracted from probe storage device **400** and placed into the shallow water tank such that a transducer **1202** mounted in probe assembly **450** is proximate the starting point referred to above. Further, probe assembly **450** includes, in one embodiment, one or more guide bars **1210**, **1212**, are utilized to mechanically connect probe assembly halves **1220** and **1222** of probe assembly **450**, with probe assembly half **1222** being movable with respect to probe assembly half **1220**. In one embodiment, magnets are utilized in probe assembly halves **1220** and **1222**, both in an attracting mode and in a repulsion mode, to move the probe assembly half **1222** such that probe assembly **450** properly engages the portion of the composite part that is to undergo NDI testing.

Figure **13** is a view of a probe assembly, including transducer **1302**. Probe assembly **1300** is referred to an upper radius and cap probe and is configured for the testing of a top cap **1400** in composite part **1402**, as shown in Figure **14**. For clarity, the mechanical interface between robot **302** and probe assembly **1300** is not shown.

The probe assembly **1500** of Figure **15** illustrates an alternative probe assembly configuration. More particularly, probe assembly **1500** incorporates a transducer **1502** positioned for testing of a side wall **1550** of a top cap **1552**. Probe assembly **1500** is sometimes referred to as a lower radius and side probe holder assembly. Figure **16** is a bottom view of probe assembly **1500** further illustrating transducer **1502**. Again for clarity, the mechanical interface between robot **302** and probe assembly **1500** is not shown.

The probe assembly **1700** of Figure **17** illustrates an alternative probe assembly configuration. More particularly, probe assembly **1700** incorporates a transducer **1702** positioned for testing of an inner radius **1750**, for example of top cap **1552**. Probe assembly **1700** is sometimes referred to as an inner radius probe holder assembly. The mechanical interface between robot **302** and probe assembly **1700** is not shown.

In use, probe assemblies of the type described herein are placed within the probe storage device **400** which is a portion of the linear unit of the robot **302**. With such a configuration, the three example probe assemblies described with respect to Figure **13-17**, and specifically the transducers for each, can be directly and permanently cabled to the electronic units associated with the individual transducers (e.g., ultrasonic arrays) for ease of use as described above with respect to Figures **4** and **11**. Specifically, when the robot has completed the use of one probe assembly, deposits it into the probe storage device **400**, and selects another probe assembly for use, a user does not have to disconnect cabling from the first to use with the second. The pulser-receivers of each probe assembly **450** are connected through the cable track to the data acquisition computer **316** to enable transfer of scan data.

Computer **316** and displays **312** and **314** are further illustrated in Figure **18**, which is one example of a data processing system **1800** includes communications fabric **1802**, which provides communications between processor unit **1804**, memory **1806**, persistent storage **1808**, communications unit **1810**, input/output (I/O) unit **1812**, and display **1814**. Communication unit **1810** provides an interface to robot **302** and the various NDI probe assemblies **450**.

Processor unit **1804** serves to execute instructions for software that may be loaded into memory **1806**. Processor unit **1804** may be a set of one or more processors or may be a multi-processor core, depending on the particular implementation. Further, processor unit **1804** may be implemented using one or more heterogeneous processor systems in which a main processor is present with secondary processors on a single chip. As another illustrative example, processor unit **1804** may be a symmetric multi-processor system containing multiple processors of the same type.

Memory **1806** and persistent storage **1808** are examples of storage devices. A storage device is any piece of hardware that is capable of storing information either on a temporary basis and/or a permanent basis. Memory **1806**, in these examples, may be, for example, without limitation, a random access memory or any other suitable volatile or non-volatile storage device. Persistent storage **1808** may take various forms depending on the particular implementation. For example, without limitation, persistent storage **1808** may contain one or more components or devices. For example, persistent storage **1808** may be a hard drive, a flash memory, a rewritable optical disk, a rewritable magnetic tape, or some combination of the above. The media used by persistent storage **1808** also may be removable. For example, without limitation, a removable hard drive may be used for persistent storage **1808**.

Communications unit **1810**, in these examples, provides for communications with other data processing systems or devices. In these examples, communications unit **1810** is a network interface card. Communications unit **1810** may provide communications through the use of either or both physical and wireless communication links.

Input/output unit **1812** allows for input and output of data with other devices that may be connected to data processing system **1800**. For example, without limitation, input/output unit **1812** may provide a connection for user input through a keyboard and mouse. Further, input/output unit **1812** may send output to a printer. Display **1814** provides a mechanism to display information to a user.

Instructions for the operating system and applications or programs are located on persistent storage **1808**. These instructions may be loaded into memory **1806** for execution by processor unit **1804**. The processes of the different embodiments may be performed by processor unit **1804** using computer implemented instructions, which may be located in a memory, such as memory **1806**. These instructions are referred to as program code, computer usable program code, or computer readable program code that may be read and executed by a processor in processor unit **1804**. The program code in the different embodiments may be embodied on different physical or tangible computer readable media, such as memory **1806** or persistent storage **1808**.

Program code **1816** is located in a functional form on computer readable media **1818** that is selectively removable and may be loaded onto or transferred to data processing system **1800** for execution by processor unit **1804**. Program code **1816** and computer readable media **1818** form computer program product **1820** in these examples. In one example, computer readable media **1818** may be in a tangible form, such as, for example, an optical or magnetic disc that is inserted or placed into a drive or other device that is part of persistent storage **1808** for transfer onto a storage device, such as a hard drive that is part of persistent storage **1808**. In a tangible form, computer readable media **1818** also may take the form of a persistent storage, such as a hard drive, a thumb drive, or a flash memory that is connected to data processing system **1800**. The tangible form of computer readable media **1818** is also referred to as computer recordable storage media. In some instances, computer readable media **1818** may not be removable.

Alternatively, program code **1816** may be transferred to data processing system **1800** from computer readable media **1818** through a communications link to communications unit **1810** and/or through a connection to input/output unit **1812**. The communications link and/or the connection may be physical or wireless in the illustrative examples. The computer readable media also may take the form of non-tangible media, such as communications links or wireless transmissions containing the program code.

In some illustrative embodiments, program code **1816** may be downloaded over a network to persistent storage **1808** from another device or data processing system for use within data processing system **1800**. For instance, program code stored in a computer readable storage medium in a server data processing system may be downloaded over a network from the server to data processing system **1800**. The data processing system providing program code **1816** may be a server computer, a client computer, or some other device capable of storing and transmitting program code **1816**.

The different components illustrated for data processing system **1800** are not meant to provide architectural limitations to the manner in which different embodiments may be implemented. The different illustrative embodiments may be implemented in a data processing system including components in addition to or in place of those illustrated for data processing system **1800**. Other components shown in Figure **18** can be varied from the illustrative examples shown.

As one example, a storage device in data processing system **1800** is any hardware apparatus that may store data. Memory **1806**, persistent storage **1808** and computer readable media **1818** are examples of storage devices in a tangible form.

In another example, a bus system may be used to implement communications fabric **1802** and may be comprised of one or more buses, such as a system bus or an input/output bus. Of course, the bus system may be implemented using any suitable type of architecture that provides for a transfer of data between different components or devices attached to the bus system. Additionally, a communications unit may include one or more devices used to transmit and receive data, such as a modem or a network adapter. Further, a memory may be, for example, without limitation, memory **1806** or a cache such as that found in an interface and memory controller hub that may be present in communications fabric **1802**.

This written description uses examples to disclose various embodiments, which include the best mode, to enable any person skilled in the art to practice those embodiments, including making and using any devices or systems and performing any incorporated methods. The patentable scope is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal languages of the claims.

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

1. A method for non-destructive inspection (NDI) of a part that incorporates multiple structural features, the method comprising:

selecting an NDI probe assembly from a plurality of NDI probe assemblies held in a probe storage device proximate the robotic arm, the selection based upon one or more of the multiple structural features associated with the part to be inspected;

engaging the selected NDI probe assembly with the robotic arm;

moving the robotic arm from the probe storage device to an inspection area to engage the selected NDI probe assembly with the part to be inspected, proximate one of the structural features of the part that is associated with the selected NDI probe assembly;

guiding the NDI probe assembly along the part in a defined path while a transducer associated with the selected NDI probe assembly provides and receives signals associated with NDI;

returning the selected NDI probe assembly to the probe storage device; and

repeating the selecting, engaging, moving, guiding, and returning steps for at least one more NDI probe assembly, each NDI probe assembly associated with at least one different structural feature of the part and communicatively coupled to a corresponding electronic assembly both when the NDI probe assembly is deployed on the robotic arm and when the NDI probe assembly is in the storage device.

2. The method according to claim **1** further comprising moving the robotic arm along a linear guide proximate the part.

3. The method according to claim **2** wherein the storage device is mechanically coupled to the robotic arm for movement along the linear track.

4. The method according to claim **1** wherein moving the robotic arm from the storage device to the inspection area comprises moving the selected NDI probe assembly into a position within a water tank, the part to be inspected disposed within the water tank.

5. The method according to claim **1** wherein guiding the NDI probe assembly along the part in a defined path comprises at least one of:

moving the robotic arm along a linear track proximate the part undergoing the NDI; and

moving a six-axis joint arm pedestal associated with the robotic arm.

6. The method according to claim **5** wherein moving the robotic arm from the storage device to the inspection area further comprises engaging the part to be inspected with a guidance fixture such that a transducer within the guidance fixture is placed proximate the part for an initial NDI scan.

7. The method according to claim **1** wherein engaging the selected NDI probe assembly with the robotic arm comprises mechanically engaging a guidance fixture within which at least one transducer is mounted.

8. A non-destructive inspection (NDI) system comprising:

a linear track comprising a carriage operable to move along said linear track;

a robotic arm mounted to said carriage;

a storage device mounted to said carriage;

a plurality of electronic assemblies mounted to said carriage, each of said electronic assemblies operable to provide signals for the operation of specific transducers utilized in NDI; and

a plurality of NDI probe assemblies disposed within said storage device communicatively coupled to a corresponding said electrical assembly, each NDI probe assembly comprising at least one transducer operable for NDI of a component and a mechanical interface to said robotic arm, for NDI of a component having a plurality of structural features, said system programmed to:

operate said robotic arm to select, engage and remove one of said NDI probe assemblies from said storage device for NDI of at least one specific structural feature,

place the removed NDI probe assembly in a position with respect to the component that causes the at least one transducer associated with the said NDI probe assembly to be proximate a start position for NDI of the at least one structural feature;

execute a command to start the NDI;

move the removed NDI probe assembly along at least one defined scan path using at least one of said carriage and said robotic arm;

return the removed NDI probe assembly to said storage device upon completion of the NDI of the structural features of the component associated with the removed NDI assembly; and

said system further programmed to repeat the operation, placement, execution, movement and returning for each of said NDI probe assemblies within said storage device needed to complete a specific set of NDI tests for a plurality of structural features associated with the component.

9. The NDI system of claim **8** wherein each said NDI probe assembly comprises:

a first probe assembly half;

a second probe assembly half; and

at least one guide bar utilized to mechanically connect said probe assembly halves, said second probe assembly half being movable with respect to said first probe assembly half, each said probe assembly half comprising at least one magnet disposed therein, said magnets operable to move said second probe assembly half such that said NDI probe assembly engages the portion of the component that is to undergo NDI.

10. The NDI system of claim **8** further comprising a water tank proximate said linear track, said linear track positioned proximate said water tank such that said robotic arm is capable of traveling the length of said water tank along said linear track.

11. The NDI system of claim **8** wherein said electronic assemblies are communicatively coupled to the corresponding said transducers both when said NDI probe assemblies are deployed on said robotic arm and when disposed within said storage device.

12. The NDI system of claim **8** wherein said NDI probe assemblies comprise:

an upper radius and cap probe assembly;

a lower radius and side probe assembly; and

an inner radius probe assembly.

13. A system for non-destructive inspection (NDI) of a part that incorporates multiple structural features, the system comprising:

a robotic arm;

means proximate the robotic arm, for storing a plurality of NDI probe assemblies associated with at least one different structural feature of the part;

means for selecting an NDI probe assembly from said plurality of NDI probe assemblies held in said means for storing, the selection based upon one or more of the multiple structural features associated with the part to be inspected;

means for engaging the selected NDI probe assembly with the robotic arm;

means for communicatively coupling each NDI probe assembly to a corresponding electronic assembly both when the NDI probe assembly is engaged with the robotic arm and when the NDI probe assembly is in the storage means;

means for moving the robotic arm from the storing means to an inspection area to engage the selected NDI probe assembly with the part to be inspected, proximate one of the structural features of the part that is associated with the selected NDI probe assembly;

means for guiding the NDI probe assembly along the part in a defined path while a transducer associated with the selected NDI probe assembly provides and receives signals associated with NDI;

means for returning the selected NDI probe assembly to the means for storing; and

means for causing the selecting, engaging, moving, guiding, and returning steps to be repeated for at least one more of said NDI probe assemblies.

14. The system according to claim **13** further comprising a linear guide proximate the part and means for moving the robotic arm along the linear guide.

15. The system according to claim **14** wherein the means for storing is mechanically coupled to the robotic arm for movement along the linear track.

16. The system according to claim **13** wherein the part to be inspected is disposed within a water tank and wherein means for moving the robotic arm from the storage means to the inspection area is operatively configured to move the selected NDI probe assembly into a position within the water tank.

17. The system according to claim **13** wherein the means for guiding the NDI probe assembly along the part in a defined path comprises at least one of:

a linear track proximate the part undergoing the NDI and means for moving the robotic arm along the linear track; and

a six-axis joint arm pedestal associated with the robotic arm and means for moving the six-axis joint arm pedestal.

18. The system according to claim **17** wherein the means for moving the robotic arm from the means for storing to the inspection area further comprises a guidance fixture having a transducer therewithin and means for engaging the part to be inspected with the guidance fixture such that the transducer is placed proximate the part for an initial NDI scan.

19. The system according to claim **13** further comprising a guidance fixture having at least one transducer mounted therein and wherein the means for engaging the selected NDI probe assembly with the robotic arm comprises mechanically engaging the guidance fixture with the robotic arm.

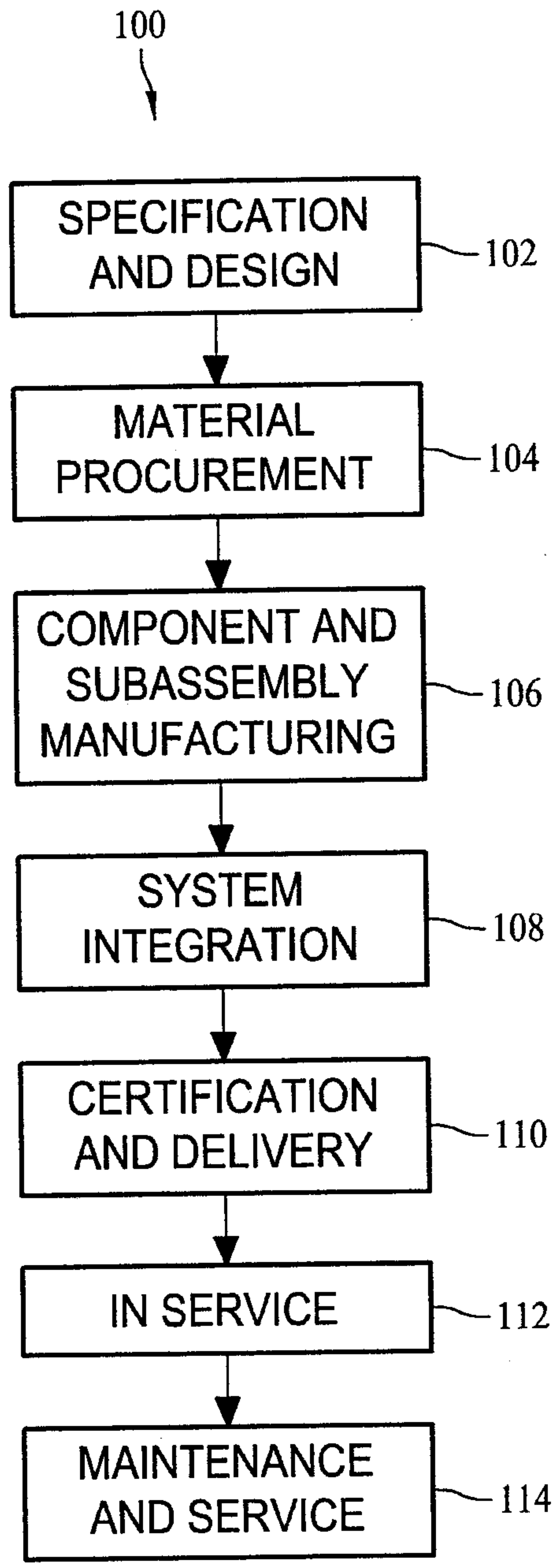

100
SPECIFICATION AND DESIGN
102
MATERIAL PROCUREMENT
104
COMPONENT AND SUBASSEMBLY MANUFACTURING
106
SYSTEM INTEGRATION
108
CERTIFICATION AND DELIVERY
110
IN SERVICE
112
MAINTENANCE AND SERVICE
114

FIG. 1

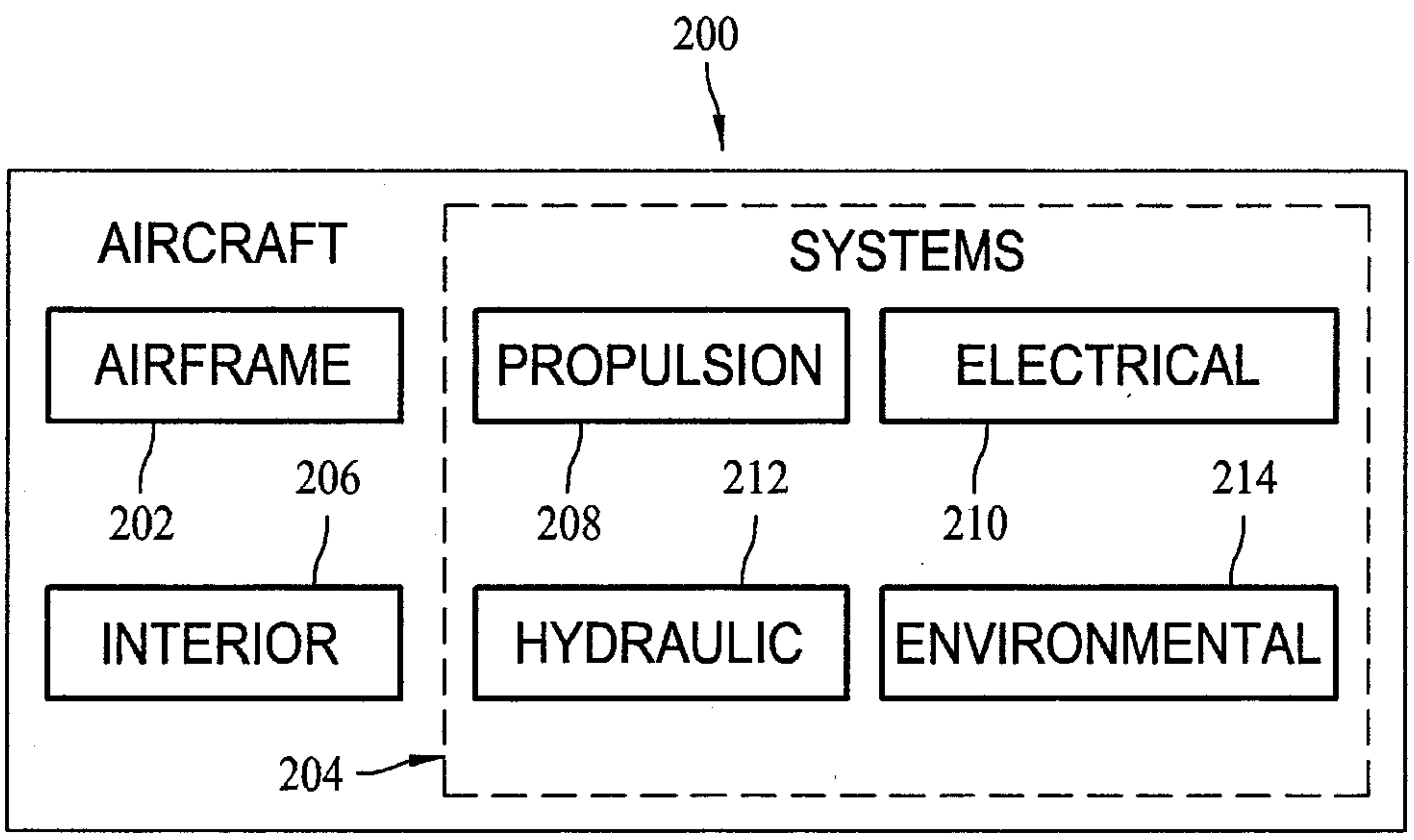

200
AIRCRAFT
SYSTEMS
AIRFRAME
PROPULSION
ELECTRICAL
202
206
208
212
210
214
INTERIOR
HYDRAULIC
ENVIRONMENTAL
204

FIG. 2

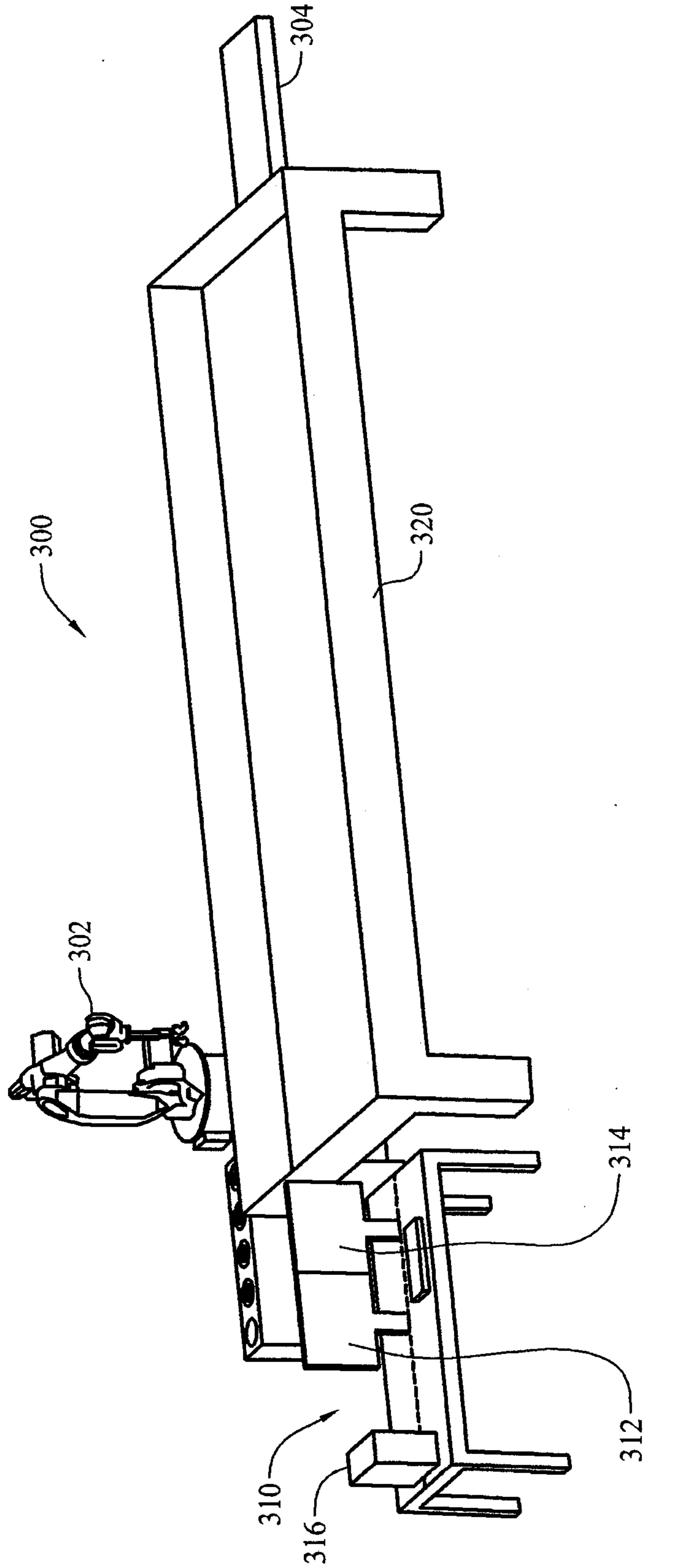


FIG. 3

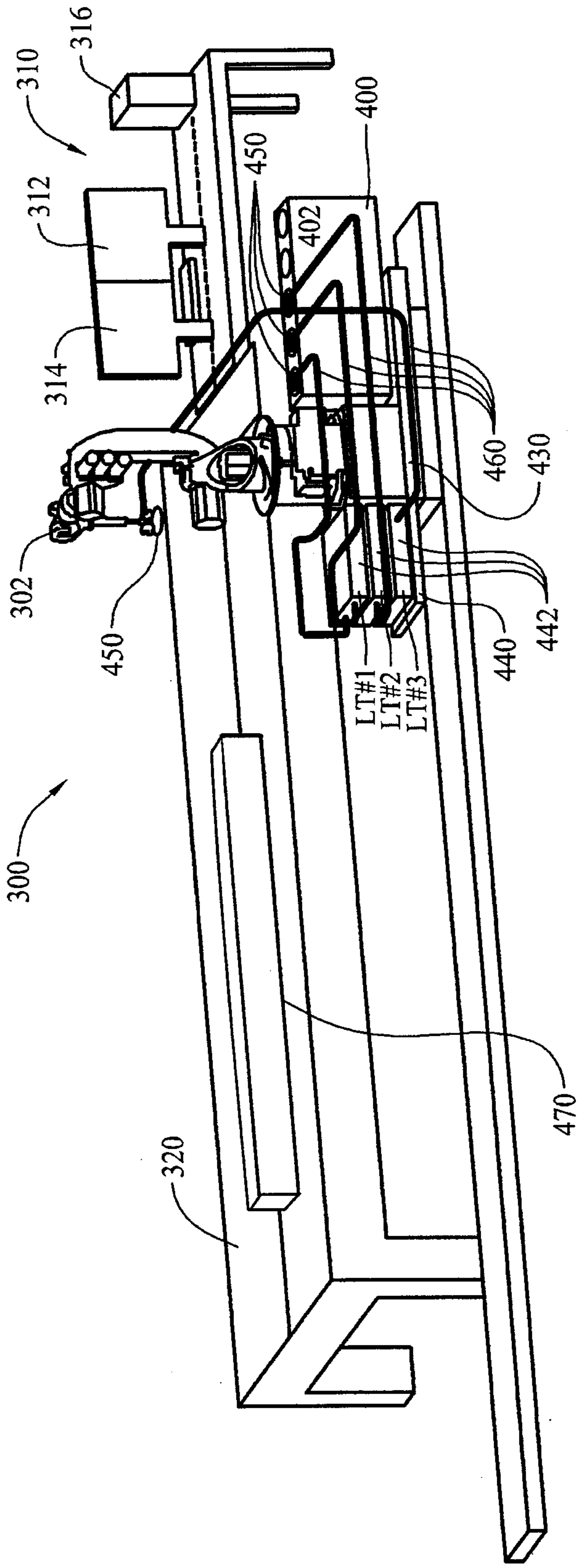

316
310
312
314
302
450
450
400
402
460
430
440
442
LT#1
LT#2
LT#3
300
470
320

FIG. 4

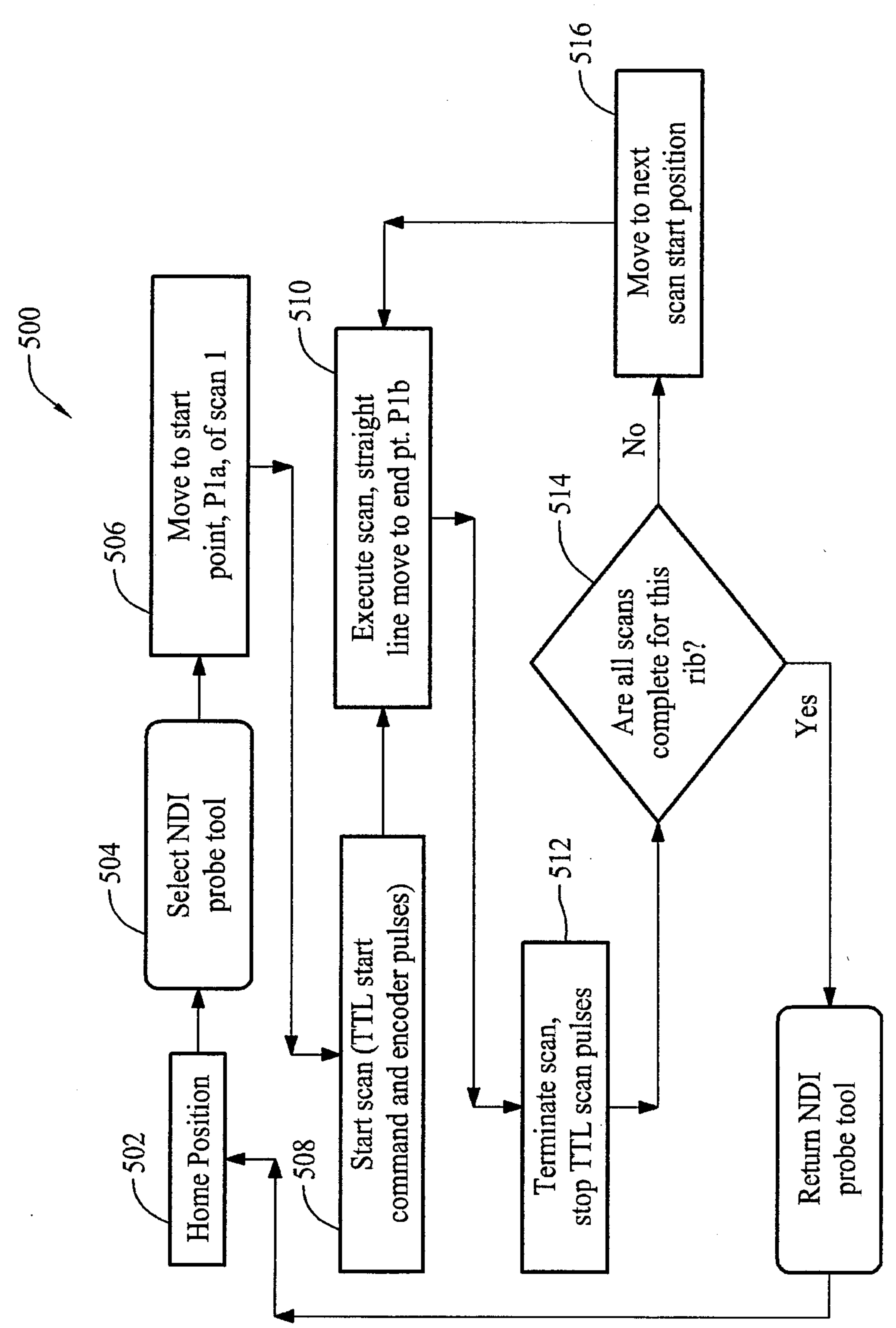

500
502
Home Position
504
Select NDI probe tool
506
Move to start point, P1a, of scan 1
508
Start scan (TTL start command and encoder pulses)
510
Execute scan, straight line move to end pt. P1b
512
Terminate scan, stop TTL scan pulses
514
Are all scans complete for this rib?
No
Yes
516
Move to next scan start position
Return NDI probe tool

FIG. 5

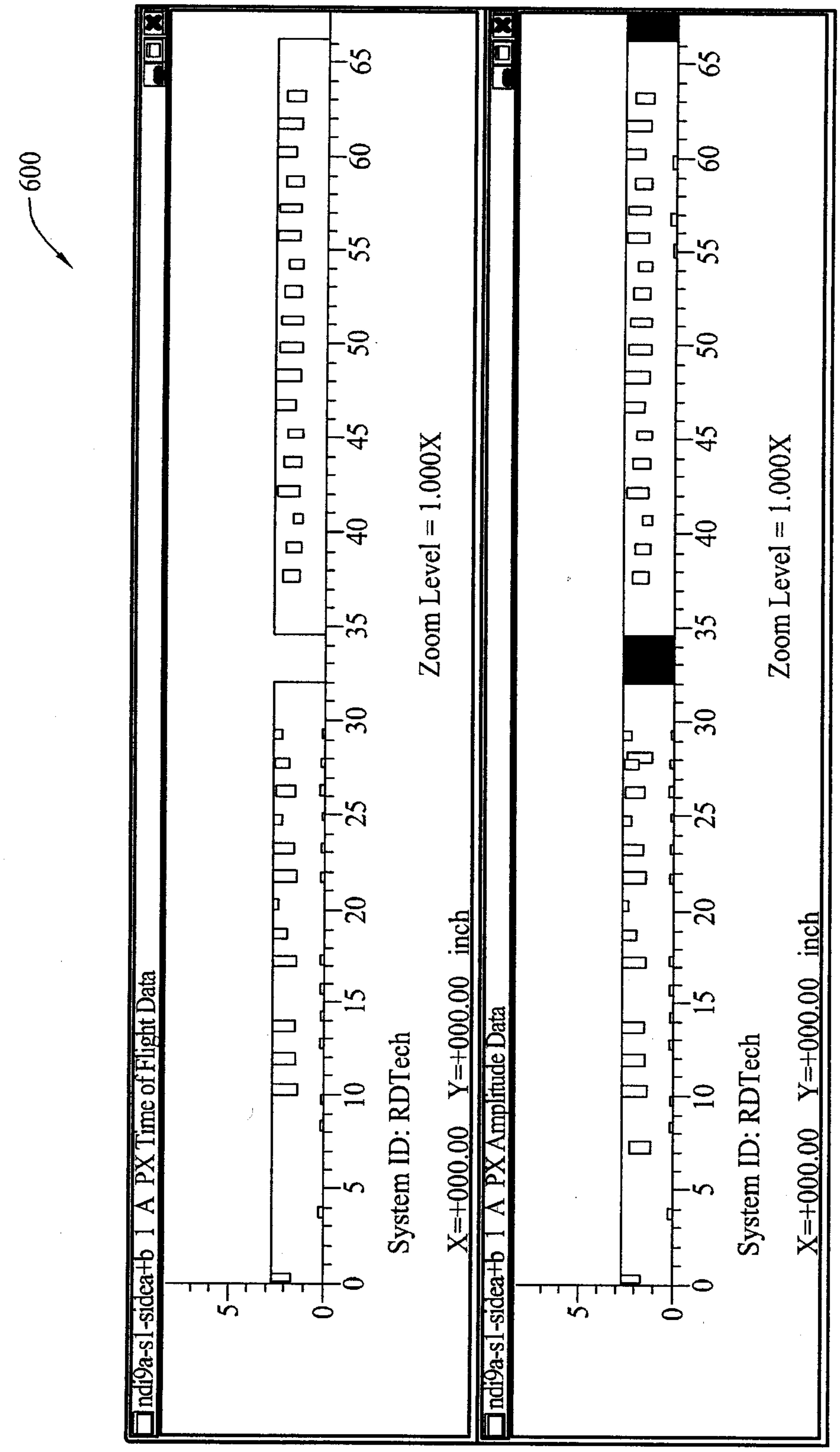

600
nd19a-s1-sidea+b 1 A PX Time of Flight Data
System ID: RDTech
X=+000.00 Y=+000.00 inch
Zoom Level = 1.000X
nd19a-s1-sidea+b 1 A PX Amplitude Data
System ID: RDTech
X=+000.00 Y=+000.00 inch
Zoom Level = 1.000X

FIG. 6

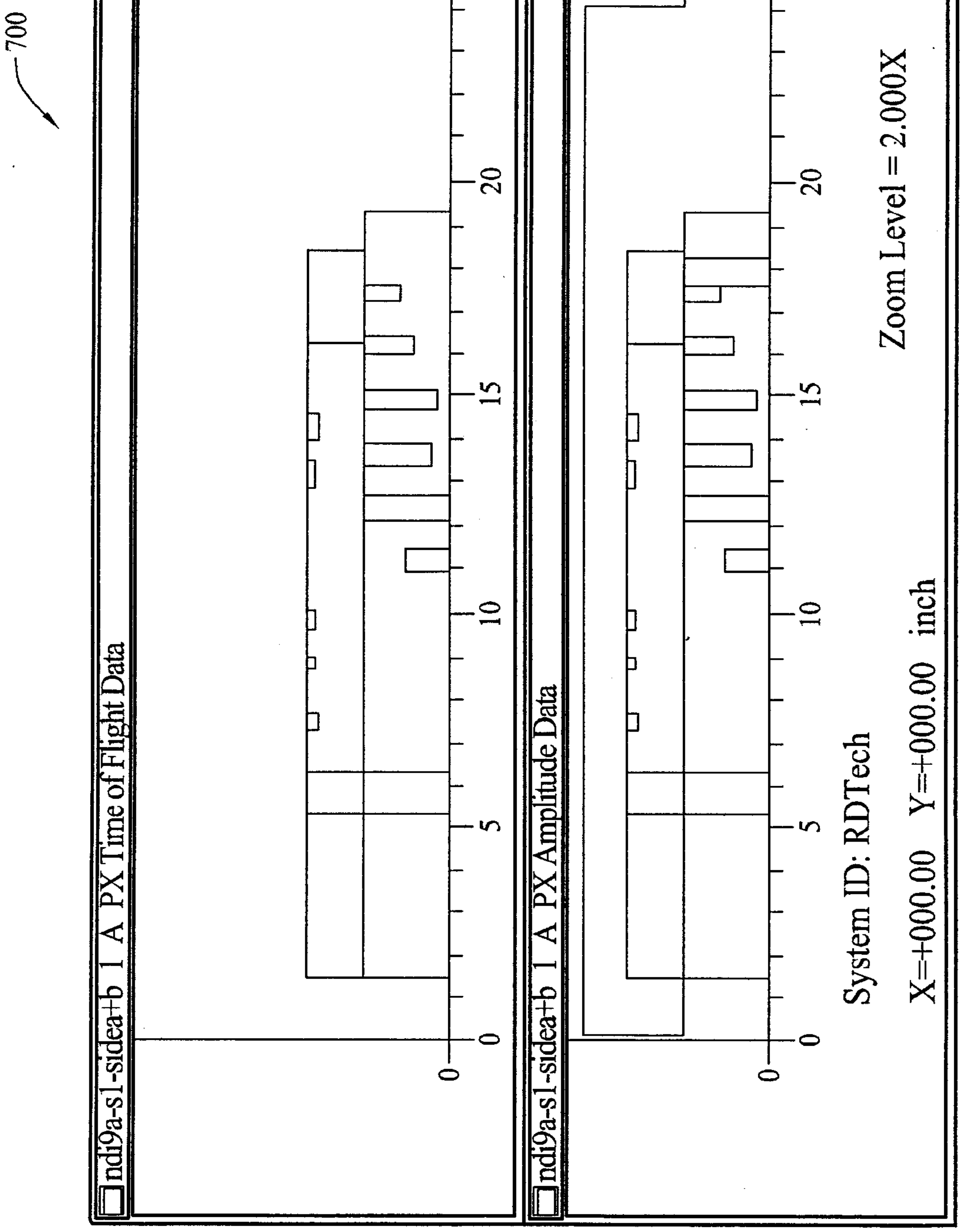

700
ndi9a-s1-sidea+b 1 A PX Time of Flight Data
0
0
5
10
15
20
25
ndi9a-s1-sidea+b 1 A PX Amplitude Data
0
0
5
10
15
20
25
System ID: RDTech
X=+000.00 Y=+000.00 inch
Zoom Level = 2.000X

FIG. 7

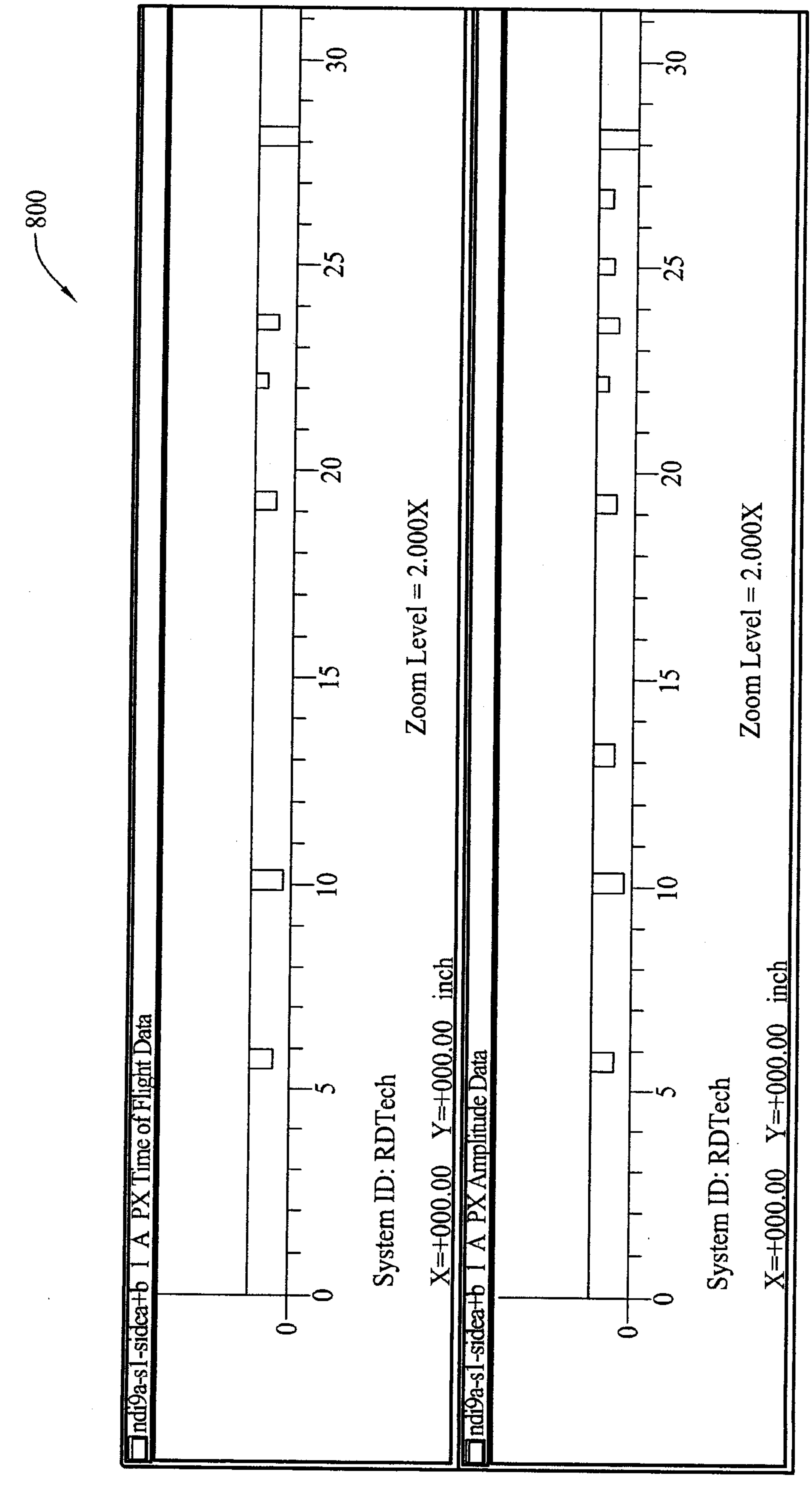

800
ndi9a-s1-sidea+b 1 A PX Time of Flight Data
0
0
5
10
15
20
25
30
Zoom Level = 2.000X
System ID: RDTech
X=+000.00 Y=+000.00 inch
ndi9a-s1-sidea+b 1 A PX Amplitude Data
0
0
5
10
15
20
25
30
Zoom Level = 2.000X
System ID: RDTech
X=+000.00 Y=+000.00 inch

FIG. 8

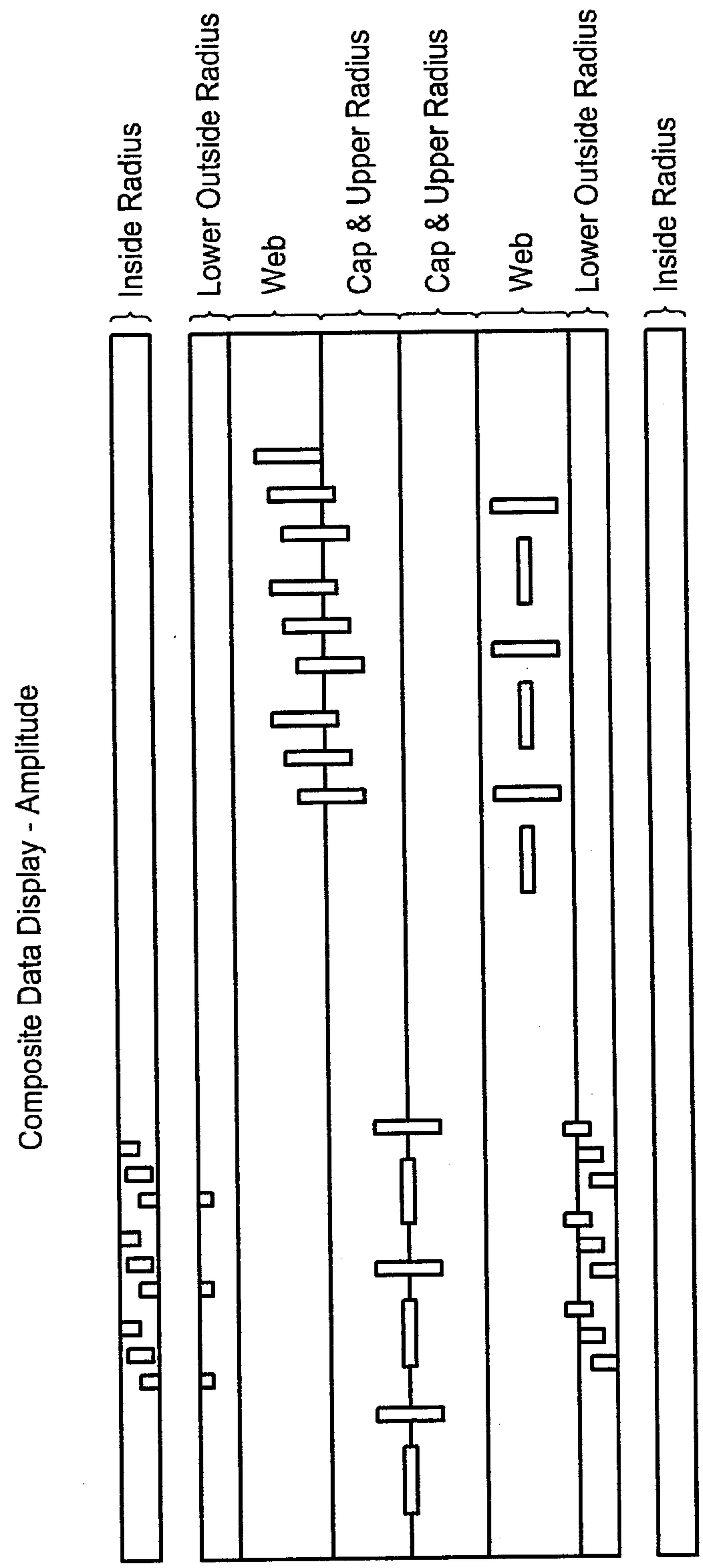

Composite Data Display - Amplitude
Inside Radius
Lower Outside Radius
Web
Cap & Upper Radius
Cap & Upper Radius
Web
Lower Outside Radius
Inside Radius

FIG. 9A

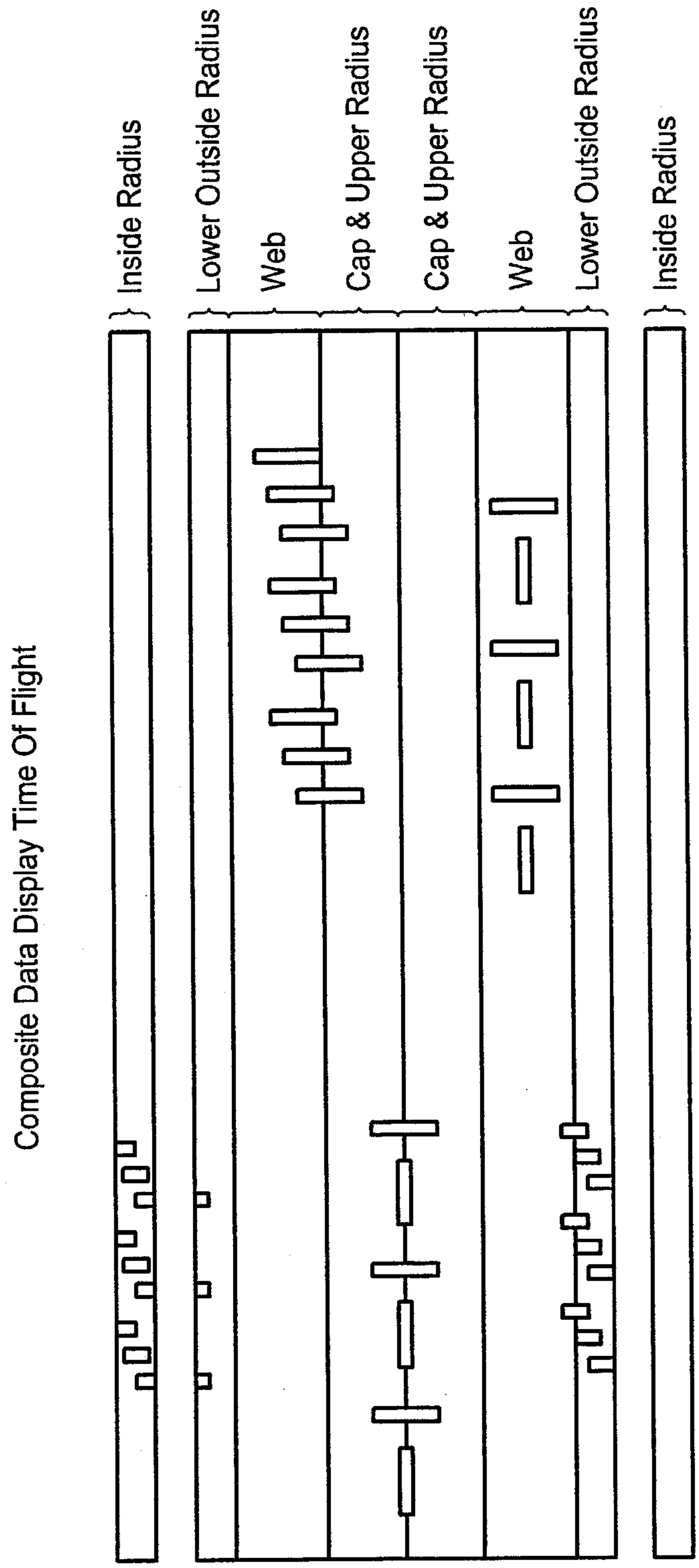

Composite Data Display Time Of Flight
Inside Radius
Lower Outside Radius
Web
Cap & Upper Radius
Cap & Upper Radius
Web
Lower Outside Radius
Inside Radius

FIG. 9B

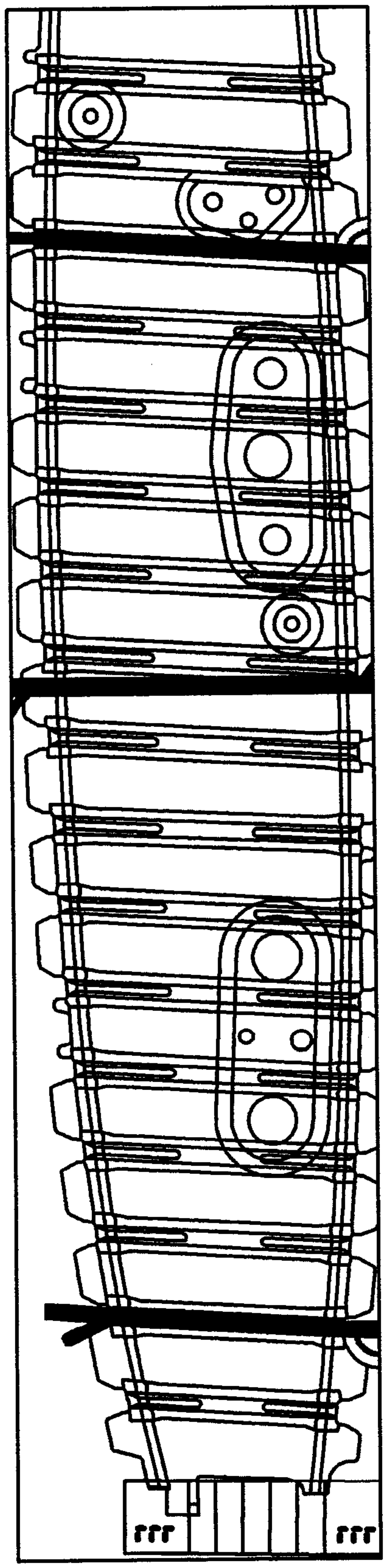


FIG. 10

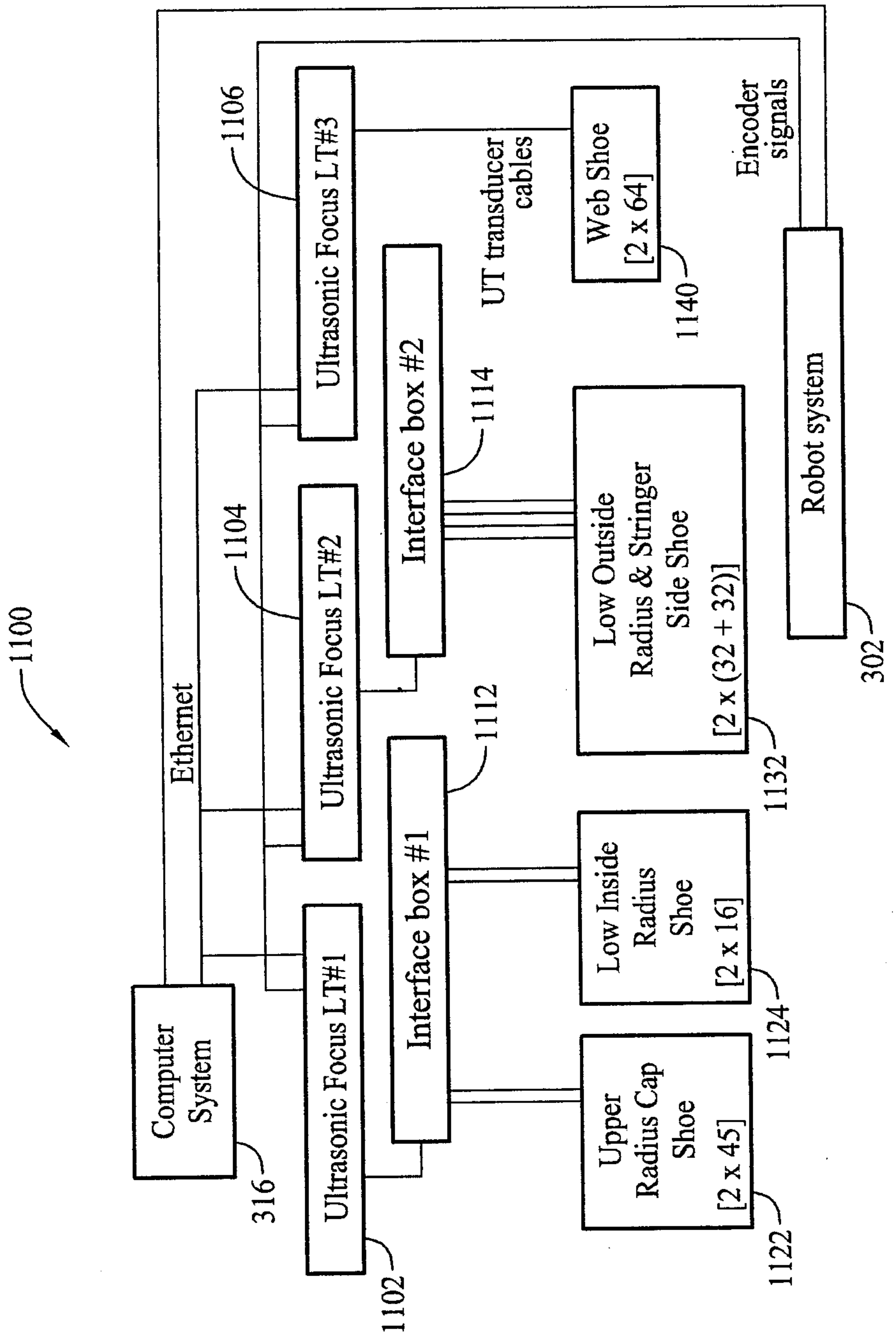

1100
Ethernet
Computer System
316
Ultrasonic Focus LT#1
1102
Ultrasonic Focus LT#2
1104
Ultrasonic Focus LT#3
1106
Interface box #1
1112
Interface box #2
1114
UT transducer cables
Web Shoe [2 x 64]
1140
Encoder signals
Robot system
302
Upper Radius Cap Shoe [2 x 45]
1122
Low Inside Radius Shoe [2 x 16]
1124
Low Outside Radius & Stringer Side Shoe [2 x (32 + 32)]
1132

FIG. 11

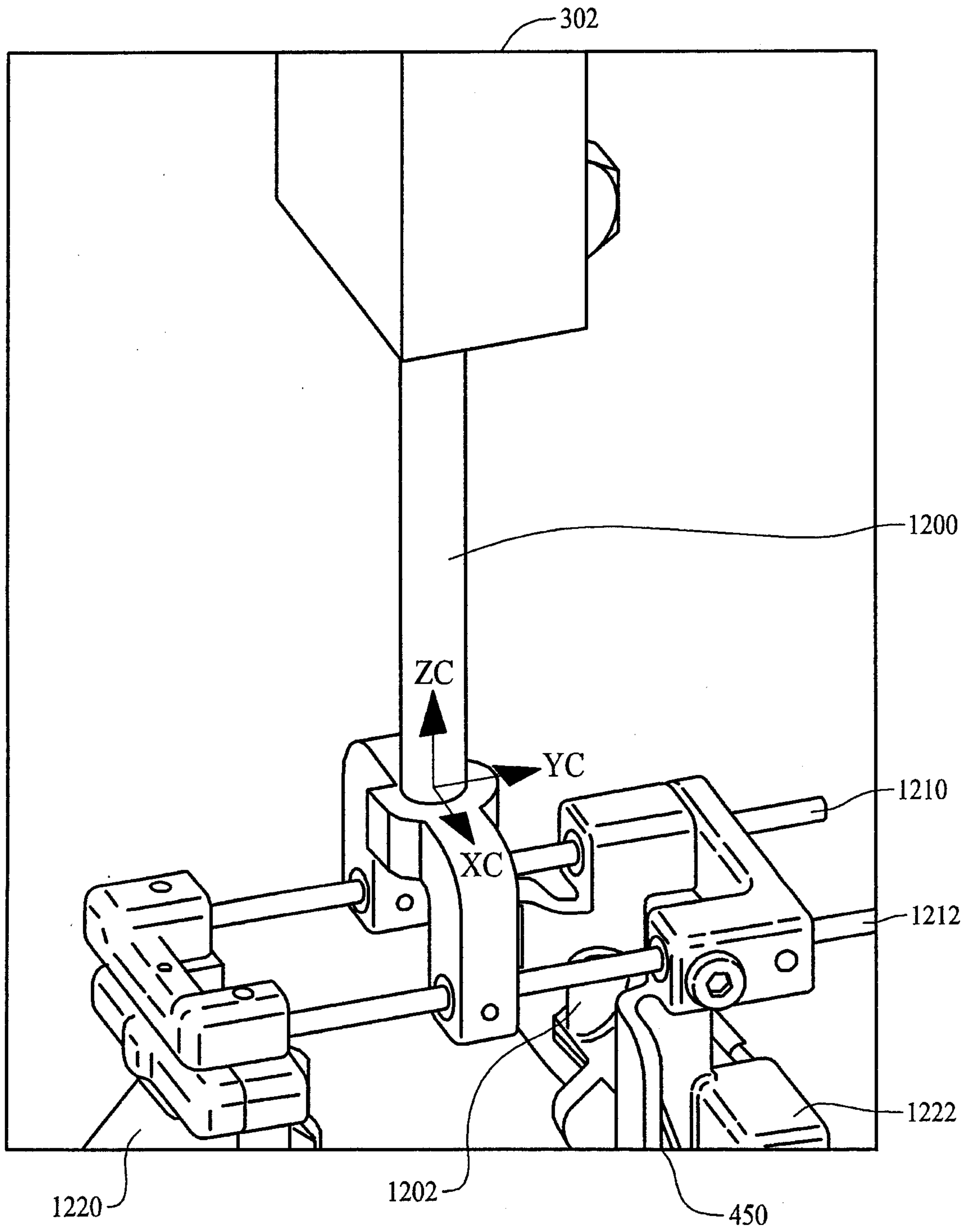


FIG. 12

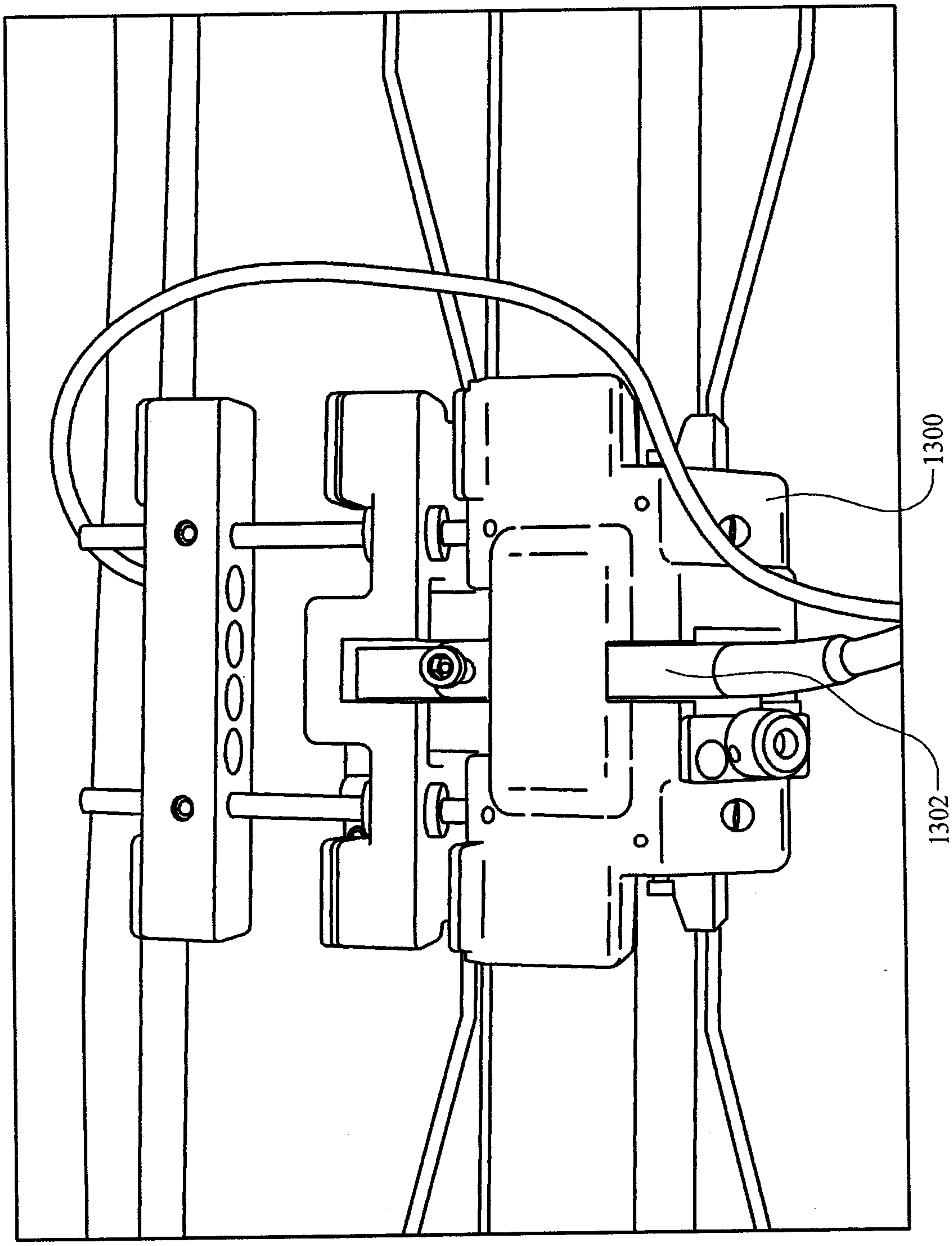


FIG. 13

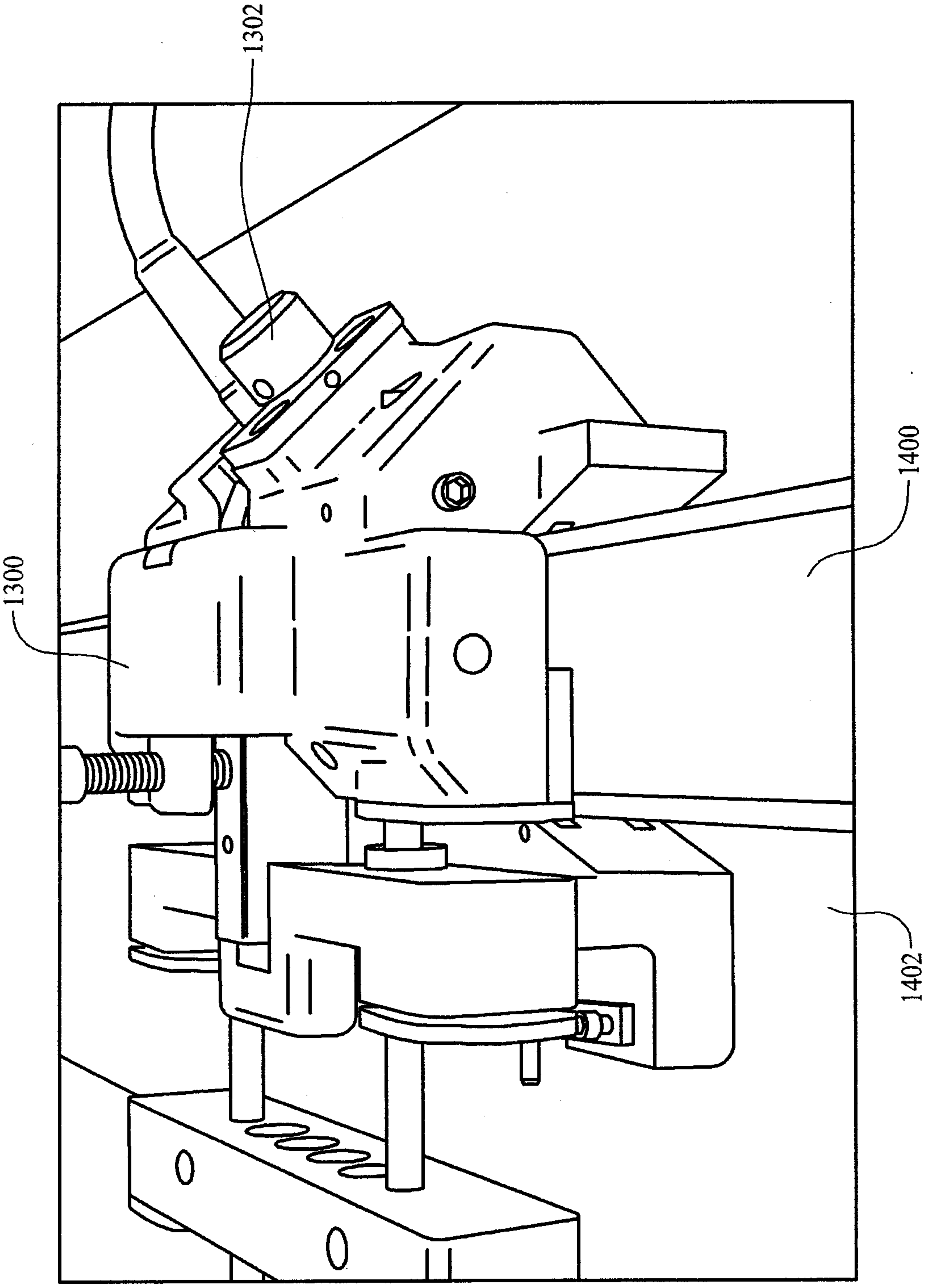


FIG. 14

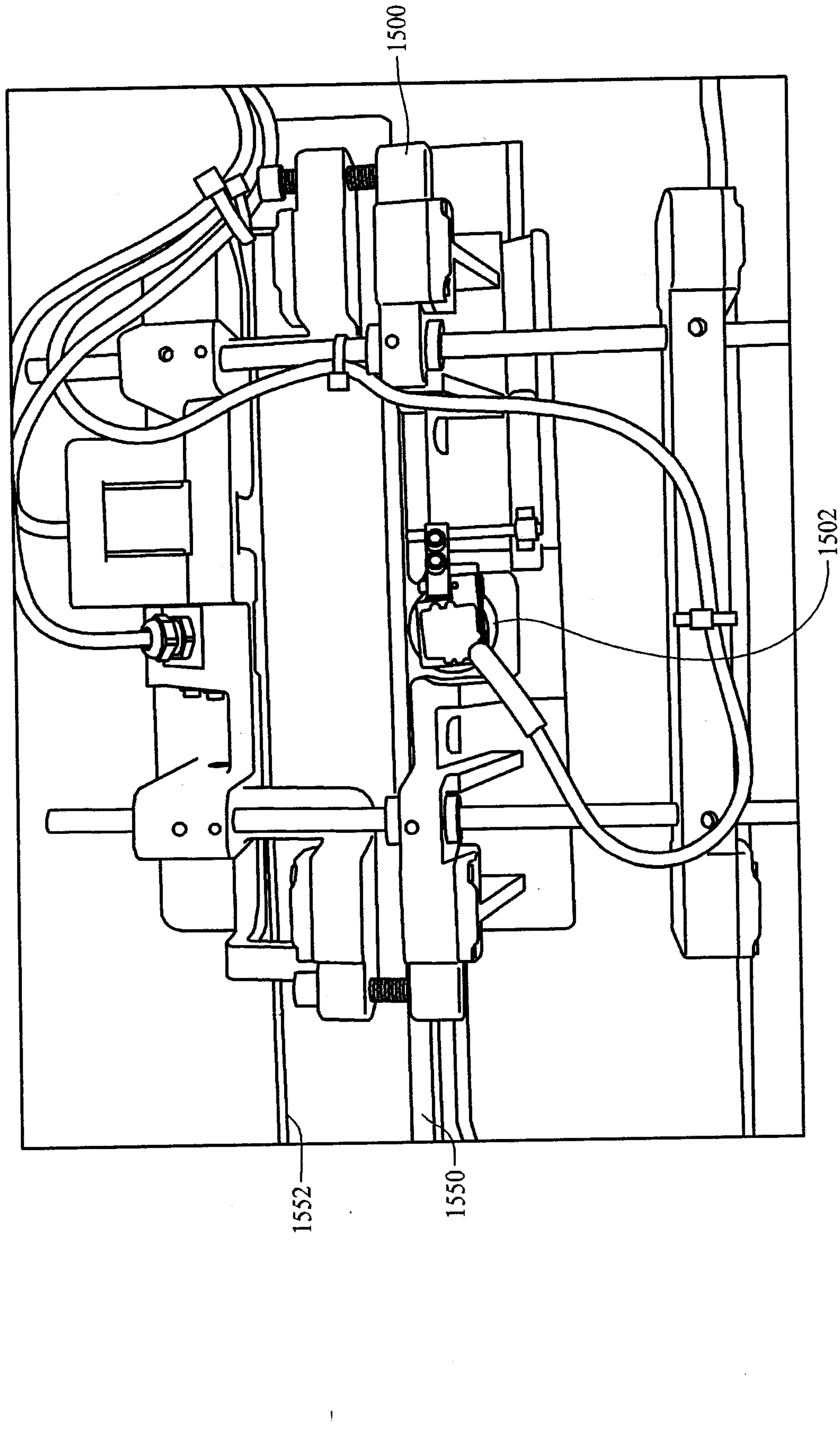


FIG. 15

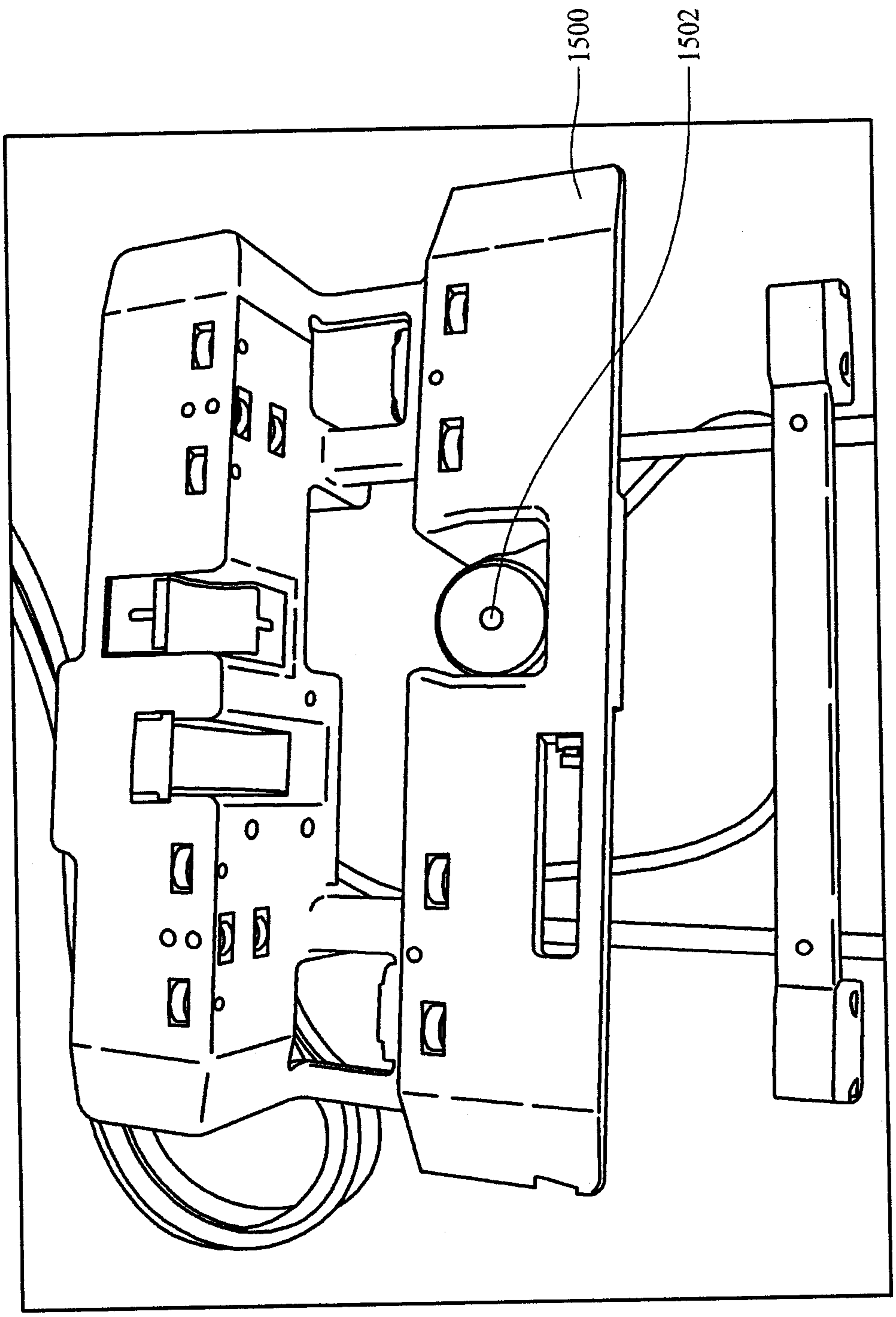


FIG. 16

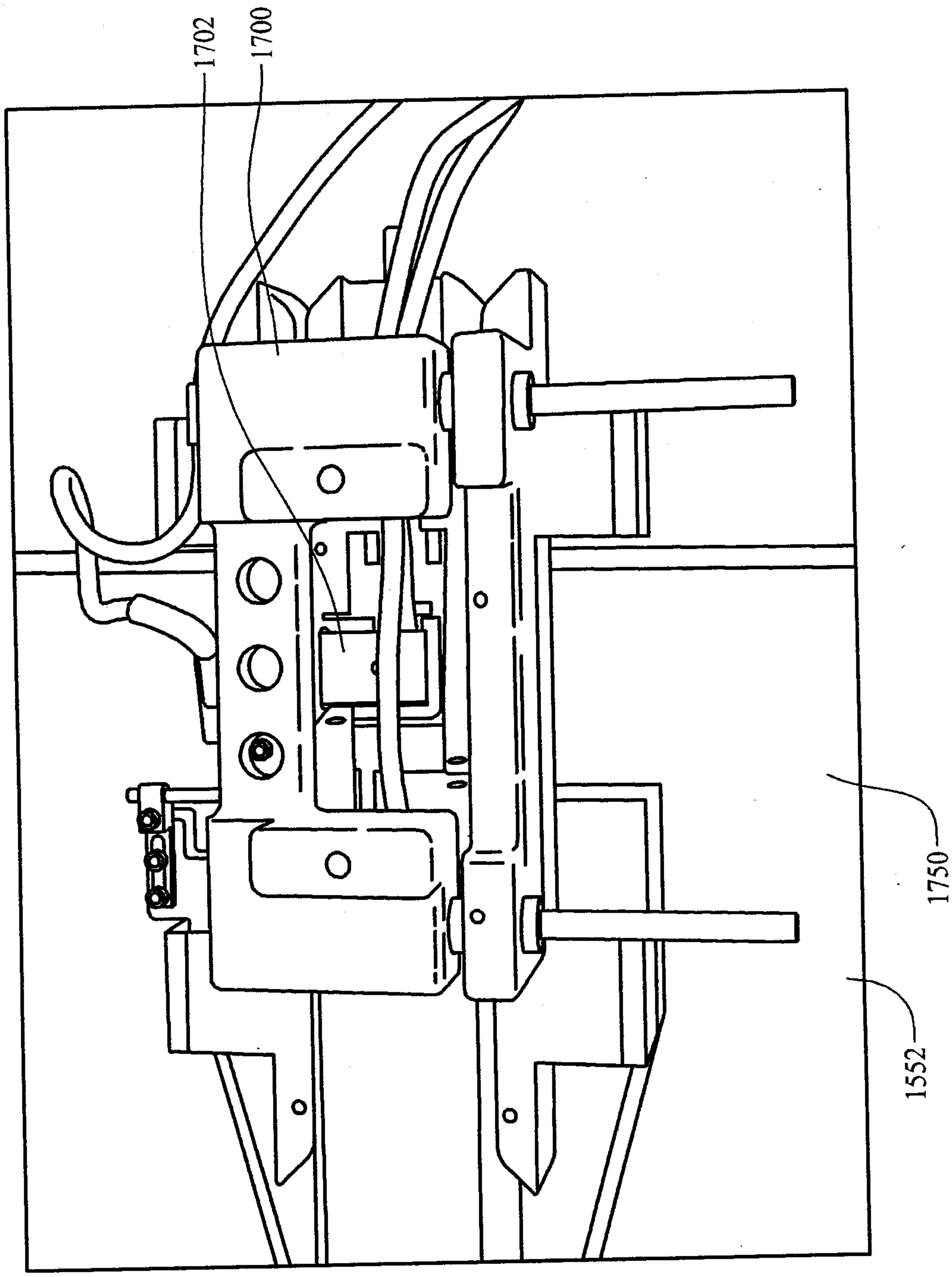


FIG. 17

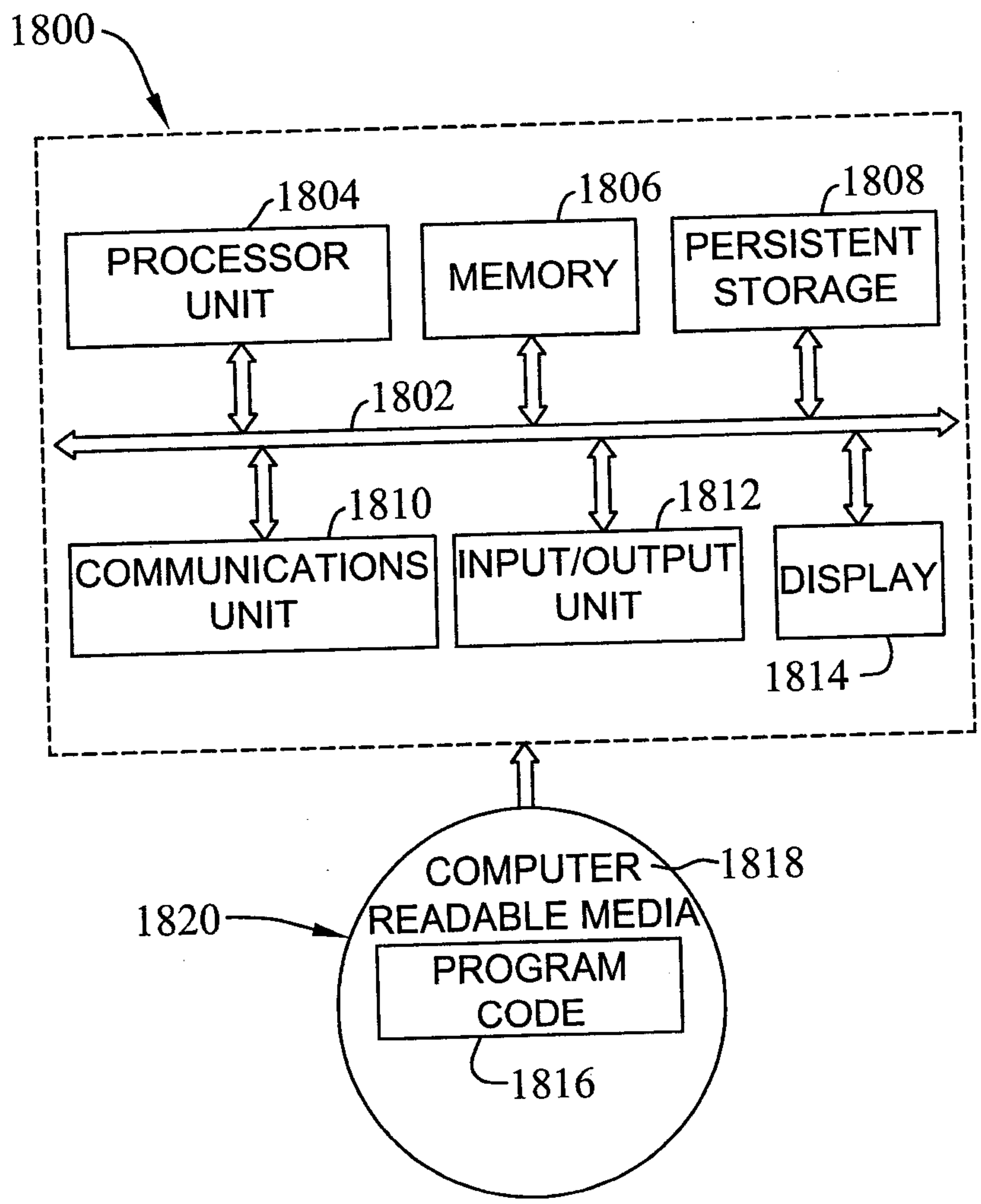

1800
1804
PROCESSOR UNIT
1806
MEMORY
1808
PERSISTENT STORAGE
1802
1810
COMMUNICATIONS UNIT
1812
INPUT/OUTPUT UNIT
DISPLAY
1814
COMPUTER READABLE MEDIA
1818
1820
PROGRAM CODE
1816

FIG. 18

300
302
310
316
304
320
312
314