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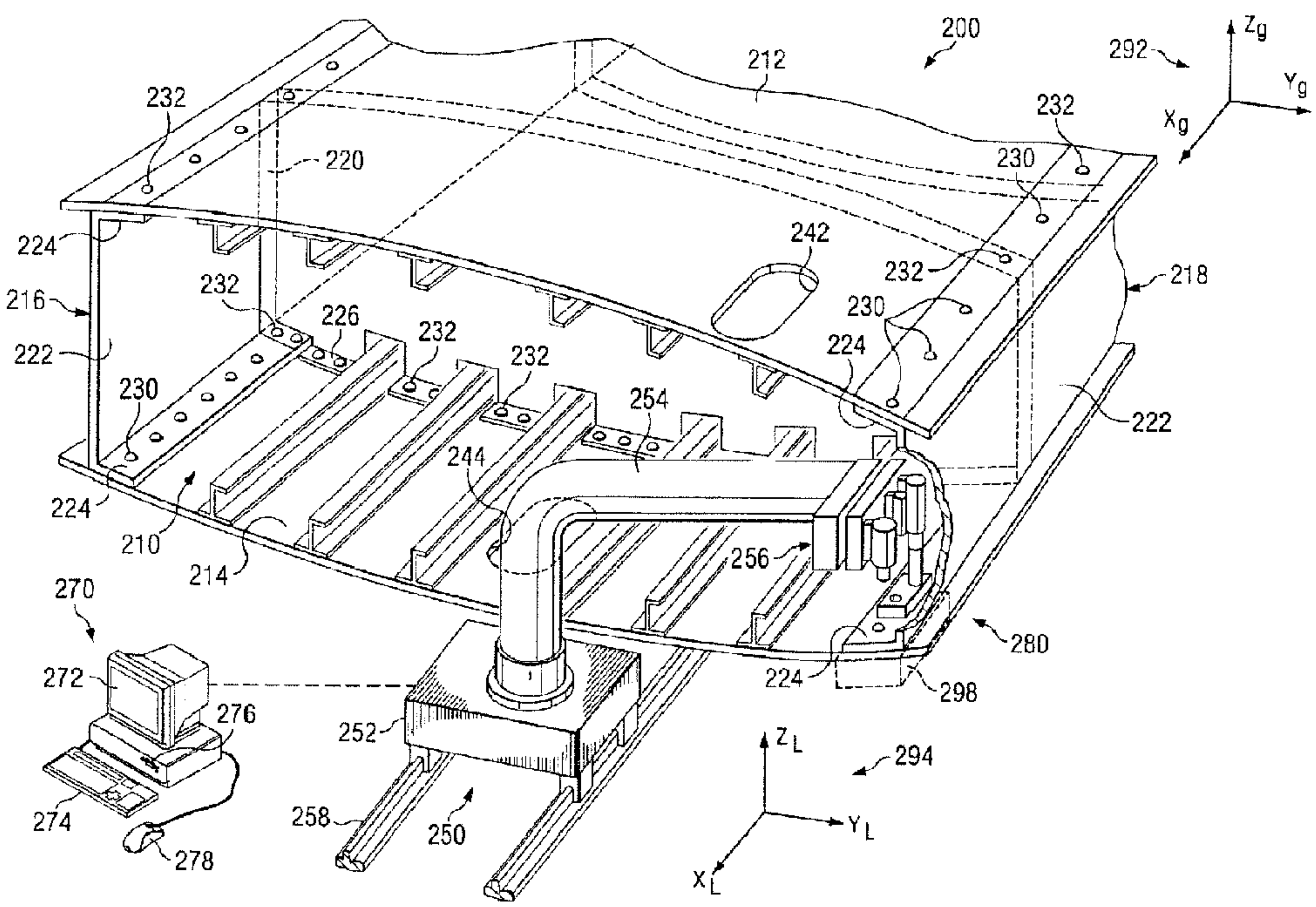
(54) **Titre : OUTIL D'ASSEMBLAGE A DEPLOIEMENT DE ROBOT ET PROCEDE D'INSTALLATION D'ATTACHES DANS DES STRUCTURES D'AERONEF**
(54) **Title: ROBOT-DEPLOYED ASSEMBLY TOOL AND METHOD FOR INSTALLING FASTENERS IN AIRCRAFT STRUCTURES**



(57) **Abrégé/Abstract:**
An assembly system for assembling a wing box of an aircraft, the wing box defining an enclosed area accessible through at least one access opening. The assembly system includes a robot located outside the wing box that extends and guides a robot arm into the enclosed area of the wing box through the at least one access opening and an assembly tool mounted to the robot arm. The assembly tool includes a positioning mechanism for positioning the assembly tool in the enclosed area; a clamp for clamping the assembly tool to an interior surface of the enclosed area of the wing box; and an electromagnet located outside the wing box positioned to activate the clamp to clamp the assembly tool to the interior surface.

ROBOT-DEPLOYED ASSEMBLY TOOL AND METHOD FOR INSTALLING FASTENERS IN AIRCRAFT STRUCTURES

ABSTRACT OF THE DISCLOSURE

An assembly system for assembling a wing box of an aircraft, the wing box defining an enclosed area accessible through at least one access opening. The assembly system includes a robot located outside the wing box that extends and guides a robot arm into the enclosed area of the wing box through the at least one access opening and an assembly tool mounted to the robot arm. The assembly tool includes a positioning mechanism for positioning the assembly tool in the enclosed area; a clamp for clamping the assembly tool to an interior surface of the enclosed area of the wing box; and an electromagnet located outside the wing box positioned to activate the clamp to clamp the assembly tool to the interior surface.

ROBOT-DEPLOYED ASSEMBLY TOOL AND METHOD FOR INSTALLING FASTENERS IN AIRCRAFT STRUCTURES

BACKGROUND

The disclosure relates generally to an assembly tool and method and, more particularly, to a robot-deployed assembly tool and method for installing fasteners in an interior area of an aircraft wing box or other structure.

When attaching wing skins to the spar caps and bulkheads using various fasteners during wing box assembly, for example, operator mechanics may be required to enter into the wing box and work with various hand tools in order to complete the assembly process. Typically, the operator locates an intended drilling location, manually drills a stack-up of spar cap and wing skin or bulkhead flange and wing skin, removes the detail parts and then performs de-burring and cleanup. The operator may then reposition the parts and align the drilled holes prior to fastener installation.

Carrying many often heavy tools and performing the highly repetitive assembly actions in an interior area of a wing box or similar structure can cause fatigue, discomfort and possible injury to the operator. Adequate lighting and ventilation must also be maintained to ensure satisfactory working conditions.

There is, accordingly, a need for a mechanism for assisting an operator in performing fastener installation or other repetitive assembly tasks without the necessity of having the operator enter into an interior area of an aircraft wing box or other structure.

SUMMARY

An embodiment of the disclosure provides an assembly system for assembling a wing box of an aircraft, the wing box defining an enclosed area accessible through at least one access opening, the assembly system providing a robot located outside the wing box that extends and guides a robot arm into the enclosed area of the wing box through the at least one access opening and an assembly tool mounted to the robot arm. The assembly tool provides a positioning mechanism for positioning the assembly tool in the enclosed area, a clamp for clamping the assembly tool to an interior surface of the enclosed area of the wing box, and an electromagnet located outside the wing box positioned to activate the clamp to clamp the assembly tool to the interior surface.

A further embodiment provides a robot arm link operably coupled to the robot arm and a connector link operably coupled to the robot arm link.

Another embodiment provides a vision module in the positioning mechanism for guiding the assembly tool to a fastener location in the enclosed area.

An embodiment provides a camera in the vision module that guides the assembly tool to a fastener location in the enclosed area by a laser beam passing through a notch in the clamp.

In another embodiment at least one of a light source and a laser sensor in the vision module is provided.

Another embodiment provides a fastener installing mechanism for installing a fastener in the hole and a securing utility tool in the fastener installing mechanism for securing a fastener securing element to the fastener.

A further embodiment provides a dispensing utility tool in the fastener securing mechanism for dispensing the fastener securing element to the fastener.

Another embodiment provides actuators in the assembly tool for moving the dispensing utility tool and the securing utility tool into dispensing and securing positions, respectively.

A further embodiment a clamping foot operably coupled to the clamp for being magnetically clamped to an interior surface of the enclosed area.

Another embodiment provides a gap between a wing spar cap and a skin panel or between a wing bulkhead flange and a skin panel that is eliminated by clamping the clamping foot to the interior surface of the enclosed area when the electromagnet located outside of the wing box activates the clamp thereby enabling substantially burr-less drilling of the hole through the wing spar cap and the skin panel or the wing bulkhead flange and the skin panel from outside of the wing box.

Another embodiment provides a taper of the clamping foot for clamping the assembly tool to the interior surface of the enclosed area at corner fastener locations.

The features, functions, and advantages can be achieved independently in various embodiments or may be combined in yet other embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

The novel features believed characteristic of the embodiments are set forth in the appended claims. The embodiments themselves, however, as well as a preferred mode of use, further objectives and advantages thereof, will best be understood by reference to the following detailed description of advantageous embodiments when read in conjunction with the accompanying drawings.

Figure 1 is an illustration of an aircraft in which advantageous embodiments of the disclosure may be implemented;

Figure 2 is an illustration of a section of a wing box for an aircraft and a robot-deployed assembly tool for assembling the wing box in accordance with an advantageous embodiment of the disclosure;

Figure 3 is an illustration of the robot arm of the robot-deployed assembly tool of **Figure 2** in accordance with an advantageous embodiment of the disclosure;

Figures 4A and **4B** are illustrations of an assembly tool module of the robot-deployed assembly tool of **Figure 2** in nested and deployed positions, respectively, in accordance with an advantageous embodiment of the disclosure;

Figures 5, **6** and **7** are illustrations showing different views of the deployed assembly tool module of **Figure 4B**;

Figure 8 is an illustration of an assembly tool module in accordance with a further advantageous embodiment of the disclosure;

Figure 9 is an illustration of a top view of the assembly tool module of **Figure 8**;

Figure 10 is an illustration of an assembly tool module in accordance with yet a further advantageous embodiment of the disclosure; and

Figure 11 is a flowchart that illustrates a method for installing fasteners in a wing box of an aircraft in accordance with an advantageous embodiment of the disclosure.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

With reference now to the figures, and, in particular, with reference to **Figure 1**, an illustration of an aircraft is depicted in which advantageous embodiments of the disclosure may be implemented. More particularly, aircraft **100** is an example of a structure in which a robot-deployed assembly tool and an assembly method in accordance with advantageous embodiments of the disclosure may be implemented.

In this illustrative example, aircraft **100** has wings **102** and **104** attached to body **106**. Aircraft **100** includes wing mounted engines **108**, **110**, **112** and **114**. Further, aircraft **100** also includes body mounted engine **116**, body mounted engine **118** and horizontal and vertical stabilizers **120** and **122**, respectively.

Figure 2 is an illustration of a section of a wing box for an aircraft and a robot-deployed assembly tool for assembling the wing box in accordance with an advantageous embodiment of the disclosure. Specifically, **Figure 2** illustrates a portion of wing box **200**, for example, although not limited to wings only, such as one of wings **102** and **104**, and robot-deployed assembly tool **250** for assembling components of wing box **200**. The interior area of wing box **200**, generally designated by reference number **210**, is an example of a confined or bounded area within which robot-deployed assembly tool **250** may be advantageously employed, although it should be understood that advantageous embodiments are not limited to employing robot-deployed assembly tool **250** in any particular area.

Wing box **200** is comprised of a plurality of components including top skin panel **212**, bottom skin panel **214**, wing spars **216** and **218**, and wing box bulkhead **220**. Wing spars **216** and **218** each include wing spar web portion **222** and wing spar cap portions **224**, and wing box bulkhead **220** includes bulkhead flanges including bulkhead flange **226**. As shown in **Figure 2**, assembly of wing box **200** requires that cap portions **224** of wing spars **216** and **218** and bulkhead flanges **226** of wing box bulkhead **220** be fastened to top and bottom skin panels **212** and **214** and to each other at numerous fastener locations, including centrally located straight fastener locations such as locations **230**, and corner fastener locations such as locations **232**, using appropriate fasteners (not illustrated in **Figure 2**). Yet other fastening operations may also be performed if needed. The fasteners may include, but are not limited to, bolts or screws that may extend through aligned openings in the components to be assembled and may be secured by nuts, collars or other suitable securing elements.

The fastening operation may require access to interior area **210** of wing box **200** and this is typically achieved, in the case of large wing boxes, by an operator entering into interior area **210** and using appropriate hand tools needed to complete the assembly process. As indicated previously, performing the highly repetitive assembly actions in the interior area of a wing box can cause fatigue, discomfort and possible injury to the operator.

Advantageous embodiments of the disclosure provide a robot-deployed assembly tool, such as robot-deployed assembly tool **250** in **Figure 2** to facilitate assembly of the components of wing box **200** by making it unnecessary for an operator to enter into interior area **210** of wing box **200**.

More particularly, robot-deployed assembly tool **250** generally comprises robot body **252**, robot arm **254** and assembly tool module

256. Robot body **252** may be mounted on track **258** for movement to desired assembly positions, although it should be understood that other mechanisms may be used to provide mobility to robot-deployed assembly tool **250**, and it is not intended to limit advantageous embodiments to any particular mechanism for moving robot-deployed assembly tool **250**. Robot arm **254** may extend from robot body **252** and carry assembly tool module **256** at the outer end thereof.

As shown in **Figure 2**, one or more access openings that are typically provided in wing box **200** for maintenance purposes and the like, may provide robot arm **254** and assembly tool module **256** attached thereto with access to interior area **210** of wing box **200**. In the advantageous embodiment illustrated in **Figure 2**, one access opening **242** is provided in top skin panel **212** and one access opening **244** is provided in bottom skin panel **214**. It should be understood, however, that the number of access openings and their positioning is intended to be exemplary only, as one or more access openings can be provided at any desired location or locations of wing box **200**.

Figure 2 illustrates robot arm **254** of robot-deployed assembly tool **250** inserted into interior area **210** of wing box **200** through access opening **244** in bottom skin panel **214**. Robot arm **254** may be extended to position assembly tool module **256** to perform fastening operations, in this example, to fasten wing spar cap **224** to bottom skin panel **214** at fastener location **280**.

After fastening operations are completed at fastener location **280**, robot arm **254** may be operated to move assembly tool module **256** to a second fastener location to perform fastening operations at the second fastener location. The process may be repeated until fastening operations have been performed at all fastening locations accessible through access opening **244**. Robot-deployed assembly tool **250** may then be moved to another access opening, for example, access opening **242**, and fastening operations may then be performed at fastener locations accessible through access opening **242**. The process may be repeated until all fastening operations have been completed.

Robot-deployed assembly tool **250** may be operated by a user from a remotely-located control console shown at **270**. Control console **270** may, for example, be a computer having video display terminal **272**, keyboard **274**, storage devices **276** which may include permanent and removable storage media, and mouse **278**. Additional input devices may also be included within computer **270** such as, for example, a joystick, trackball, touchpad and the like.

Figure 3 is an illustration of robot arm **254** of robot-deployed assembly tool **250** of **Figure 2** in accordance with an advantageous embodiment of the disclosure. Robot arm **254** may include a plurality of links including first link **302** connected to robot base **252** in **Figure 2**, last link **304** having assembly tool module **256** in **Figure 2** attached thereto, as will be described hereinafter, and a plurality of intermediate links including links **306** and **308**. The links of robot arm **254** may be positioned relative to each other and to interior area **210** by hydraulically, electrical or pneumatically actuated control mechanisms, not shown, known to a person with ordinary skill in the art. The control mechanisms may move robot arm **254** between a nested position (not shown in **Figure 3**) in which robot arm **254** is fully retracted and an extended position in which the arm is fully extended (also not shown). In the advantageous embodiment illustrated in **Figure 3**, the links are configured as C-channel-shaped links and may be retracted or extended by rotating one link with respect to another. It should be understood, however, that robot arm **254** can be formed of links of other suitable configurations, for example, links in the form of blocks of rectangular cross-section, and the links may be extended and retracted by other mechanisms without departing from advantageous embodiments.

Figures 4A and **4B** are illustrations of assembly tool module **256** shown in **Figure 2** in nested **401** and deployed **403** positions, respectively. **Figures 5**, **6** and **7** are illustrations of different views of the deployed assembly tool module **256** of **Figure 4B**. The directions of the different views are indicated by arrows in **Figure 4B** referring to each of **Figures 5-7**. **Figure 7** illustrates assembly tool module **256** with various portions, including utility tools **450** and **452**, removed for clarity. Assembly tool module **256** may include several components which are described in detail below with reference to **Figures 4A**, **4B** and **5-7**.

Connector link **402** is attached to last link **304** of robot arm **254**, and may function as an interface between the robot arm and an assembly tool generally designated by reference number **406**.

As best shown in **Figure 4B**, connector link **402** may be mounted to robot arm link **304** via a deploying mechanism, generally designated by reference number **410**, that may include, but is not limited to, a motor and an appropriate set of gears to rotate the connector link and the assembly tool mounted thereto relative to robot arm link **304** between nested position **401** shown in **Figure 4A** and deployed position **403** shown in **Figure 4B**.

In the advantageous embodiment illustrated in **Figures 4A-7**, robot arm links are configured as C-channel-shaped links as illustrated in **Figure 3**, and connector link **402** is also configured as a C-channel-shaped link and is sized to be received within robot arm link **304** when in nested position **401** shown in **Figure 4A**. It should be understood, however, that connector link **402** may be of other appropriate configurations, and it is not intended to limit advantageous embodiments to any particular configuration.

Connector link **402** may support vision module **412** and actuator mechanism **414** that provides for rotation of assembly tool **406** as will be described hereinafter. Connector link **402** may be connected to assembly tool **406** via a plurality of hinges **416** connected to back plate **422** as will also be described more fully hereinafter.

Vision module **412** may include camera **472**, light source **474** and laser sensor **476**. As best shown in **Figure 4B**, vision module **412** may be movable up and down along rails **427** between a stowed position (not shown) within connector link **402** for protection before deployment of assembly tool module **256** from robot arm link **304**, and a deployed position shown in **Figure 4B**. An operator may use camera **472** and light source **474** of vision module **412** to guide movement of robot arm **254** within interior area **210** of wing box **200**. Laser sensor **476** may serve as a position check for an intended drilling location. Vision module **412** may also be used to check for drilling quality after a drilling operation has been performed, for example, without limitation, to check the diameter and roundness of a drilled hole, hole edge distance and its perpendicularity to the drilled surface, and, in general, may be used to inspect the overall fastening operation.

As best shown in **Figure 5**, assembly tool **406** may be connected to connector link **402** by three plates, referred to herein as back plate **422**, middle plate **424** and front plate **426**. As indicated above, back plate **422** may be hinged to the top of connector link **402** by four hinges **416** to provide for outward rotation of assembly tool **406** relative to connector link **402**. Back plate **422** may include two vertical rails **428** on the front surface thereof.

Middle plate **424** may include two vertical grooves **430** and horizontal rail **432**, and front plate **426** may include horizontal groove **434** and round stud **436**, shown in **Figure 7**. Vertical rails **428** of back plate **422** may be slidably received in vertical grooves

430 of middle plate **424** so that the middle plate can glide up and down along the vertical rails. Horizontal rail **432** of middle plate **424** may be received in horizontal groove **434** of front plate **426**, so that the front plate may glide horizontally relative to the middle plate. Round stud **436** may provide a mounting and rotation for assembly tool housing **440** through rotation actuator **442** mounted at the top corner of front plate **426**.

Tool assembly housing **440** is a frame that may support various utility tools carried by assembly tool **406** and may include a set of mounting and sliding plates for the utility tools. Tool motion actuator **446** may be attached to a side plate at the top of the housing.

Utility tools of assembly tool **406** according to an advantageous embodiment may include dispensing tool **450** for dispensing a collar/nut/washer and securing tool **452** for securing a collar/nut dispensed by dispensing tool **450**. As will be described hereinafter, both dispensing tool **450** and securing tool **452** may be movable up and down by tool motion actuator **448** away from and toward a drilled hole so as to be able to perform their functions.

Clamping foot **454** may be attached to the lower legs of housing **440** via four bolts **456**. Clamping foot **454** may be formed of steel or another suitable material and enables electromagnetic clamping to be achieved in conjunction with operation of an external portable electromagnet illustrated at **298** in **Figure 2**. Clamping foot **454** functions to stabilize and clamp components being drilled/assembled between clamping foot **254** and the portable magnet, and may eliminate any gap between the components prior to drilling. This clamping process may enable substantially burr-less drilling of a hole through the components. Clamping foot **454** may include fork-like cutouts **458** extending from either end to avoid interference with fasteners when the foot is moved to and set at new drilling locations. Hole **460** in clamping foot **454** may provide drilling clearance. Channel notch **462** may be included in clamping foot **454** to provide an open path for a laser beam from vision module **412** to help locate a drilling position.

In general, clamping foot **454**, housing **440** and utility tools **450** and **452** comprise a subassembly of assembly tool **406** that may be moved to maintain tool perpendicularity to a drilled surface. The subassembly enjoys the combinations of two rotations (rotation **405** shown in **Figure 5** and rotation **407** shown in **Figure 7**) and two translations (vertical **409** and horizontal **411** as shown in **Figure 5**) for minor positioning adjustment. **Figure 6** illustrates various motions and actions generally available using assembly tool module **256**, using a table and correspondingly numbered arrows. According to advantageous embodiments, all motions and utility tool actions may be either pneumatically, electrically or hydraulically powered and remotely controlled by control console **270**, via various actuators, linkages, etc., from external of the interior area within which the robot-deployed assembly tool is to operate. It should be understood, however, that other forms of power and remote control mechanisms may also be utilized and it is not intended to limit exemplary embodiments of the disclosure to any specific manner of control.

Assembly tool module **256** illustrated in **Figures 4A-7** may be particularly effective at fastener locations that are centrally located within a wing box (referred to as straight fastener locations **230** in **Figure 2**). Robot mobility of the assembly tool module **256** illustrated in **Figures 4A-7** may be limited in corner fastener locations (referred to as corner fastener locations **232** in **Figure 2**) by structural interference. **Figure 8** is an illustration of an assembly tool module **256** in accordance with a further advantageous embodiment of the disclosure. **Figure 9** is an illustration of a partial top view of assembly tool module **256** of **Figure 8** looking in the direction of arrows **9 - 9** in **Figure 8**. The assembly tool module **256** shown in **Figures 8** and **9** may be particularly suitable for performing fastening operations at corner locations such as corner fastener locations **232** in **Figure 2**. Assembly tool module **256** in **Figures 8** and **9** may be advantageously attached to a second robot arm (not shown) that will work side-by-side with assembly tool module **256** shown in **Figures 4A-7** that may carry utility tools for straight fastener locations.

Assembly tool module **256** may include transition plate **802**, shown in **Figures 8** and **9**, which replaces housing **440** of assembly tool **406** illustrated in **Figures 4A-7**. Transition **plate 802** may be connected to a group of motion control plates (back plate **822**, middle plate **824** and front plate **826)** that may be similar to plates **422**, **424** and **426** in assembly tool module **256** shown in **Figures 4A-7**. Transition plate **802** maintains the rotational ability of assembly tool **806** with respect to front motion control plate **826** and may provide the building foundation for new tool components. To reach corner fastener locations with agility, assembly tool module **256** shown in **Figures 8** and **9** may possess four additional degrees of freedom (one shaft rotation illustrated by arrow **803** and three tool translations illustrated by arrows **805**, **807**, and **809** in **Figure 8**).

Utility bracket **810** may be attached to transition plate **802**. Utility bracket **810** provides tool shaft support, and may also house front vision module **812**, actuator **814** and a rack and glide track, generally designated by reference number **816**.

Front vision module **812** may be located at the upper left side of utility bracket **810**. Front vision module **812** may include camera **892**, light source **894**, and laser unit **896**, and may be provided in addition to a back vision module (not shown in **Figures 8** and **9**).

Front vision module **812** may further help an operator navigate the robot deployed assembly tool within the interior area **210** of wing box **200**.

Rack and pinion drive **815** is a set of gears to provide rotary tool shaft motion that switches and positions the utility tools for a desired hole location. The rack may glide on a track attached to utility bracket **810** while the pinion may be keyed to rotary tool shaft **818**.

Rotary tool shaft **818** enables the switching of utility tools **850** and **852** and clamping foot **860**. Upper shaft lock **820** and a lower pin (not shown) keep shaft **818** in place on utility bracket **810**. The lower end of shaft **818** may be attached to tool deploy platform **870**.

Tool deploy platform **870** may be a T-shaped component at the lower end of rotary shaft **818**. It may hold utility tools **850** and **852**, clamping foot **860**, and their respective activation actuators. The combinations of rotating tool shaft and actuator motions facilitate the deployment of utility tools **850** and **852** and clamping foot **860**.

Tool motion guide set **872** is a linear motion guidance that may consist of slider **874**, guide housing **876** and tool holder **878** for each tool. The linear motion may be initiated by actuator **880** using, for example, either a hydraulically, electrical or pneumatically powered piston rod.

Tapered clamping foot **860** occupies a central position of tool deploy platform **870**. It may be attached to angle holder **882** for easy reach and to avoid interference. Clamping may be activated by, but is not limited to, an external electromagnet **298**, shown in **Figure 2**, through a stack of aluminum skin and spar cap or aluminum skin and bulkhead flange of a typical wing box.

Figure 10 is an illustration of an assembly tool module **256** in accordance with yet a further advantageous embodiment of the disclosure. The assembly tool module **256** shown in **Figure 10** may be similar to assembly tool module **256** illustrated in **Figures 8** and **9**.

Assembly tool module **256** shown in **Figure 10** differs from assembly tool module **256** shown in **Figures 8** and **9** in that dispensing tool **1050** and securing tool **1052** may be deployed with swing-arm features. Specifically, clamping foot **1060** maintains clamping throughout an entire cycle for one fastener installation. This may help ensure precise burr-less drilling and may reduce cycle time by not having to release and retract the foot between dispensing and securing operations as in assembly tool module **256** illustrated in **Figures 8** and **9**. Assembly tool module **256** shown in **Figure 10** provides many controllable motions. **Figure 10** also illustrates the various motions and actions that may be available using assembly tool module **256** using a table and correspondingly numbered arrows.

Components of assembly tool module **256** shown in **Figure 10** may include dispensing tool swing arm **1090** and securing tool swing arm **1092**. Dispensing tool swing arm **1090** may be fitted to rotary tool shaft **1018** and may be swung around shaft **1018** using actuator **1094** attached to tool deploy platform **1070**. Dispensing tool **1050** may be attached to arm **1090** and hence swings with the arm.

Securing tool swing arm **1092** may be similar to dispensing tool swing arm **1090** and controls the position of securing tool **1052**. It may be attached to the opposite side of tool deploy platform **1070** and may be caused to swing by actuator **1096**.

In operation, a robot arm, not shown in **Figure 10**, may position assembly tool module **256** at a desired drilling location within a wing box, also not shown in **Figure 10**. Clamping of the assembly tool module **256** to an internal surface of the wing box may be activated by an external electromagnet and maintained during drilling and fastener placement operations. With the foot clamping still in place, actuator **1094** on tool deploy platform **1070** may swing dispensing tool **1050** and position it over the tail portion of a fastener in coordination with tool translation actuator **1098**. The dispensing tool **1050** may then retract to a default position after dispensing a collar/nut. With the foot clamping still activated, securing tool **1052** may be swung by actuator **1096** to position securing tool **1052** over the dispensed collar/nut, again in coordination with its tool translation actuator **1098**, to secure the collar/nut to the fastener.

Securing tool **1052** may then be retracted to a default position (not shown), the clamping may be deactivated and the robot arm may retract assembly tool module **1000** and move it to a next fastener location.

To use the robot-deployed assembly tool **250** in accordance with advantageous embodiments of the disclosure, fixed global coordinate information, illustrated at **292** in **Figure 2**, may be stored in control console **270** to control general robot movements. In addition, fine positioning adjustments (illustrated by local coordinates **292** in **Figure 2**) may be performed by the assembly tool module using control console **270**.

Figure 11 is a flowchart that illustrates a method for installing fasteners in a wing box of an aircraft, such as wing box **200** of aircraft **100** in accordance with an advantageous embodiment of the disclosure. The method is generally designated by reference number **1100** and may begin by moving a robot-deployed assembly tool **250** along tracks **258** to the vicinity of an access opening **244** in a wing box **200** to be assembled (Step **1102**). Nested links, e.g., links **302-308**, of a robot arm **254** of the robot-deployed assembly tool **250** carrying an assembly tool module **256** may then be inserted through the access opening **244** and into an interior area **210** of the wing box **200** (Step **1104**).

A connector link **402** of the assembly tool module **256** may then be deployed from the last link **304** of the robot arm **254** to ready a vision module **412** on the connector link **402** for deployment (Step **1106**). The deployed vision module **412** may then be used to guide robot movement, and the links **302-308** of the robot arm **254** may be deployed successively, for example, by rotating one nested link with respect to another, to guide the assembly tool module **256** to a desired fastener location in the interior area **210** of the wing box **200** (Step **1108**). An assembly tool **406** of the assembly tool module **256** may then be precisely positioned through local adjustment (Step **1110**). A camera **472** and laser sensor **476** in the vision module **412** may be used to assist a user at control console **270** in performing this fine adjustment, for example, by moving a cursor on video display terminal **272** using mouse **278**.

A determination may be made as to whether the assembly tool **406** is correctly positioned (Step **1112**). If the assembly tool **406** is not correctly positioned (No output of Step **1112**), the method may return to step **1110** for further local adjustment of the assembly tool **406** by the user. If the assembly tool **406** is correctly positioned (Yes output of Step **1112**), electro-magnetic clamping of the assembly tool to an interior surface of the wing box **200** may be externally activated by the user using an external electromagnet **298** (Step **1114**).

Drilling of a hole through wing box components to be assembled, e.g., wing spar cap **224** and bottom skin panel **214**, may then be performed from externally of the wing box **200** (Step **1116**). Such drilling operation may include hole preparation such as countersinking, for example. Because of the clamping operation, any gap between the two components being drilled is substantially eliminated resulting in substantially burr-less drilling. The camera **472** and laser sensor **476** may be used by the user at control console **270** to check the drilled hole after the drilling operation to determine whether the hole is of an acceptable quality, both inside and outside the hole (Step **1118**). If the hole is not of acceptable quality (No output of Step **1118**), the hole may be corrected as needed, for example, by a further drilling operation (Step **1120**).

If the drilled hole is of acceptable quality (Yes output of Step **1118**), an operator may then insert a fastener such as a bolt or screw into and through the drilled hole from the exterior of the wing box **200** (Step **1122**), and a dispensing utility tool, for example, dispensing tool **450** of tool assembly **406** may be caused to deliver a fastener securing element such as a collar or nut to the inserted fastener (Step **1124**). An embodiment may include various size collars or nuts and the mechanism to install the various size collars or nuts. The dispensing utility tool **450** may then be moved away to make room for a subsequent utility tool to follow. A securing utility tool, for example, securing utility tool **452** of tool assembly **406** may then be moved into position (Step **1126**) and caused to perform required operations to permanently attach the fastener by use of the securing device acting on the fastener, such as gripping, swaging and/or tail-pin breaking operations on the fastener securing element (Step **1128**), and the assembly tool **406** may then be moved so that the dispensing utility tool will be in the default position for the next fastener installation operation (Step **1130**).

The clamping may then be deactivated (Step **1132**), and a determination may be made whether there are more fastener locations accessible through the access opening **244** at which fasteners are to be installed (Step **1134**). If there are more fastener locations

(Yes output of Step **1134**), the robot arm **254** may retract the tool **406** and guide the tool **406** to another fastener location (Step **1136**) and the method may return to Step **1110** for processing/installing a fastener at the new location.

If there are no further fastener locations accessible through the access opening **244** (No output of Step **1134**), a determination may be made as to whether there are any further access openings through which the robot-deployed assembly tool **250** should be inserted to install additional fasteners (Step **1138**). If there are further access openings, for example, access opening **242** (Yes output of Step **1138**), the robot-deployed assembly tool **250** may be withdrawn and moved to the next access opening **242** (Step **1140**) and the method returns to Step **1104**. If there are no more access openings (No output of Step **1138**), the robot-deployed assembly tool **250** may be moved along tracks **258** to a stand-by position (not shown) for the next assembly operation (Step **1142**), and the process sequence ends. The stand-by position may be a storage location remote from the wing box **200** at which the robot-deployed assembly tool **250** is stored for later use.

The description of advantageous embodiments has been presented for purposes of illustration and description, and is not intended to be exhaustive or limited to the form disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art. For example, although advantageous embodiments are described in connection with assembling a wing box for an aircraft, the embodiments may also be used to assemble other types of structures such as structures associated with ships and other vehicles and buildings. Also, the assembly tool according to advantageous embodiments can include different or additional utility tools to perform different or additional assembly operations. For example, the assembly tool can also include a drilling utility tool to drill holes from inside a structure being assembled rather than causing the holes to be drilled from the exterior of the structure. 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 features and practical applications, and to enable others of ordinary skill in the art to understand various embodiments with various modifications as are suited to particular uses that are contemplated.

CLAIMS

What is claimed is:

1. An assembly system for assembling a wing box of an aircraft, the wing box defining an enclosed area accessible through at least one access opening, the assembly system comprising:

a robot located outside the wing box that extends and guides a robot arm into the enclosed area of the wing box through the at least one access opening; and

an assembly tool mounted to the robot arm, the assembly tool comprising:

a positioning mechanism for positioning the assembly tool in the enclosed area;

a clamp for clamping the assembly tool to an interior surface of the enclosed area of the wing box; and

an electromagnet located outside the wing box positioned to activate the clamp to clamp the assembly tool to the interior surface.

2. The assembly system according to claim 1, further comprising:
a robot arm link operably coupled to the robot arm; and
a connector link operably coupled to the robot arm link.

3. The assembly system according to claim 1, further comprising:

a vision module in the positioning mechanism for guiding the assembly tool to a fastener location in the enclosed area.

4. The assembly system according to claim 3, further comprising a camera in the vision module that guides the assembly tool to a fastener location in the enclosed area by a laser beam passing through a notch in the clamp.

5. The assembly system according to claim 4, further comprising:
at least one of a light source and a laser sensor in the vision module.

6. The assembly system according to claim 1, further comprising:
a fastener installing mechanism for installing a fastener in the hole;
a securing utility tool in the fastener installing mechanism for securing a fastener securing element to the fastener.

7. The assembly system according to claim 6, further comprising:
a dispensing utility tool in the fastener securing mechanism for dispensing the fastener securing element to the fastener.

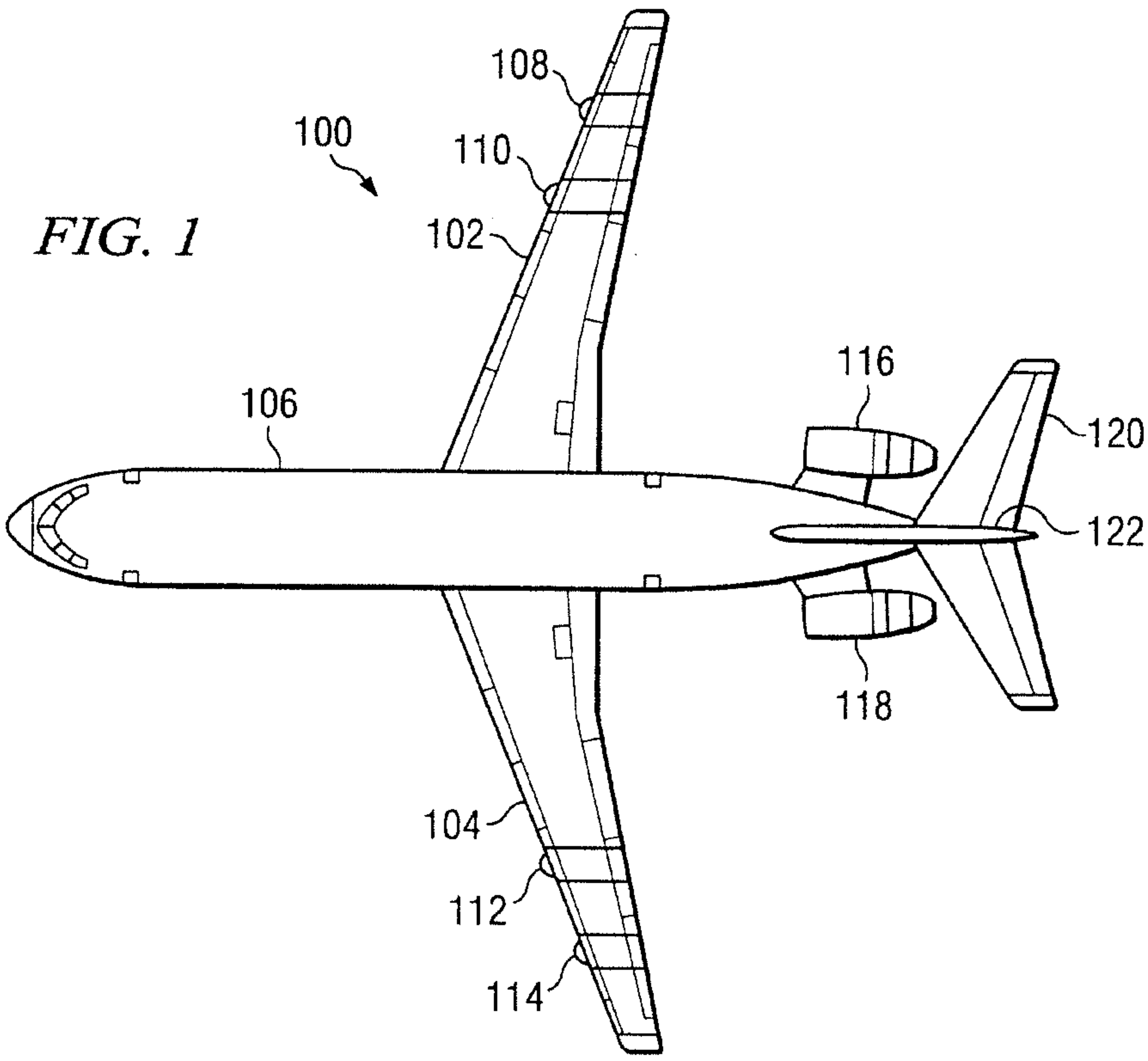
8. The assembly system according to claim 7, further comprising:
actuators in the assembly tool for moving the dispensing utility tool and the securing utility tool into dispensing and securing positions, respectively.

9. The assembly system according to claim 1, further comprising:
a clamping foot operably coupled to the clamp for being magnetically clamped to an interior surface of the enclosed area.

10. The assembly system according to claim 9, further comprising:
a gap between a wing spar cap and a skin panel or between a wing bulkhead flange and a skin panel that is eliminated by clamping the clamping foot to the interior surface of the enclosed area when the electromagnet located outside of the wing box activates the clamp thereby enabling substantially burr-less drilling of the hole through the wing spar cap and the skin panel

or the wing bulkhead flange and the skin panel from outside of the wing box.

11. The assembly system according to claim 9, further comprising: a taper of the clamping foot for clamping the assembly tool to the interior surface of the enclosed area at corner fastener locations.


100
108
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114

FIG. 1

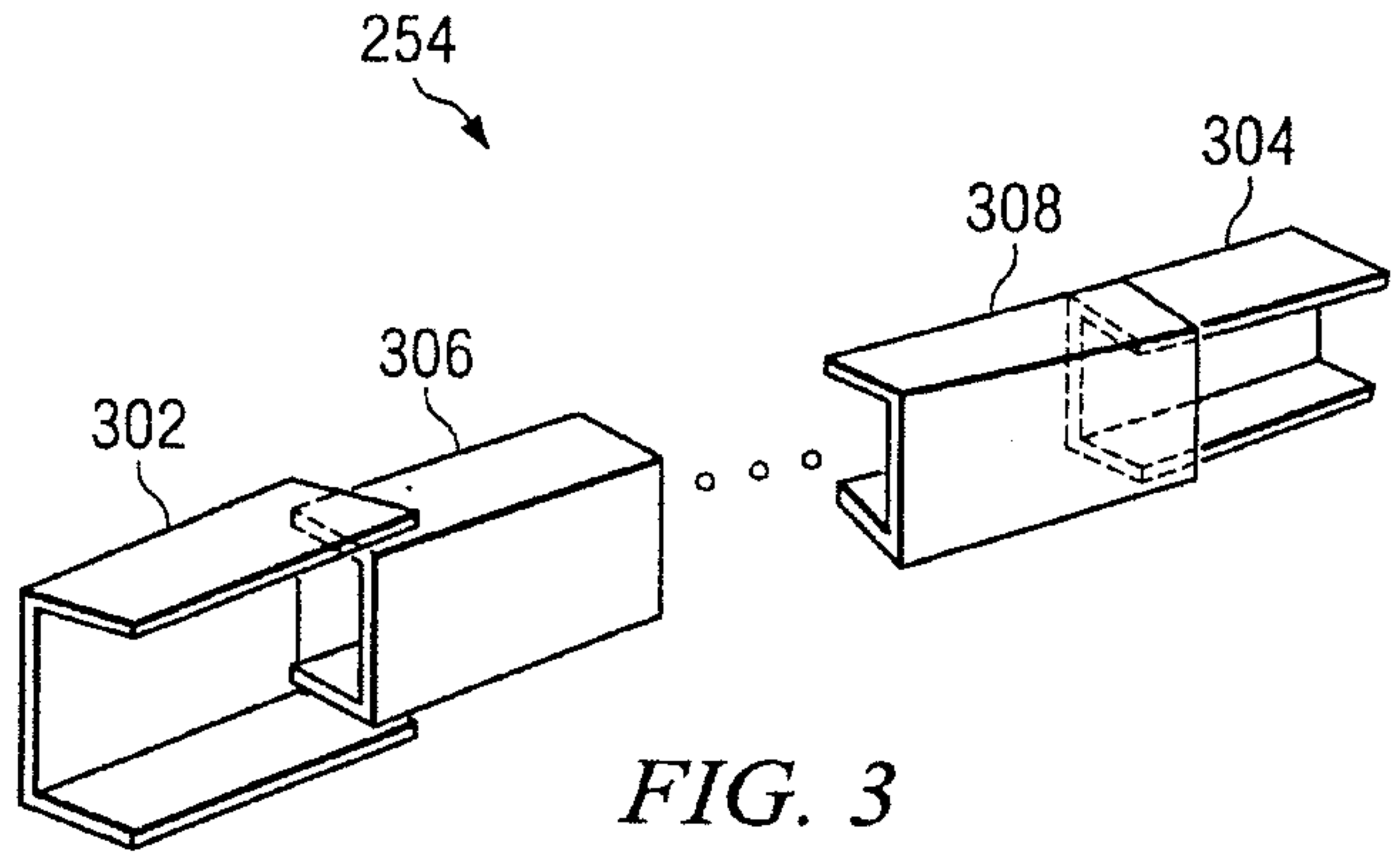
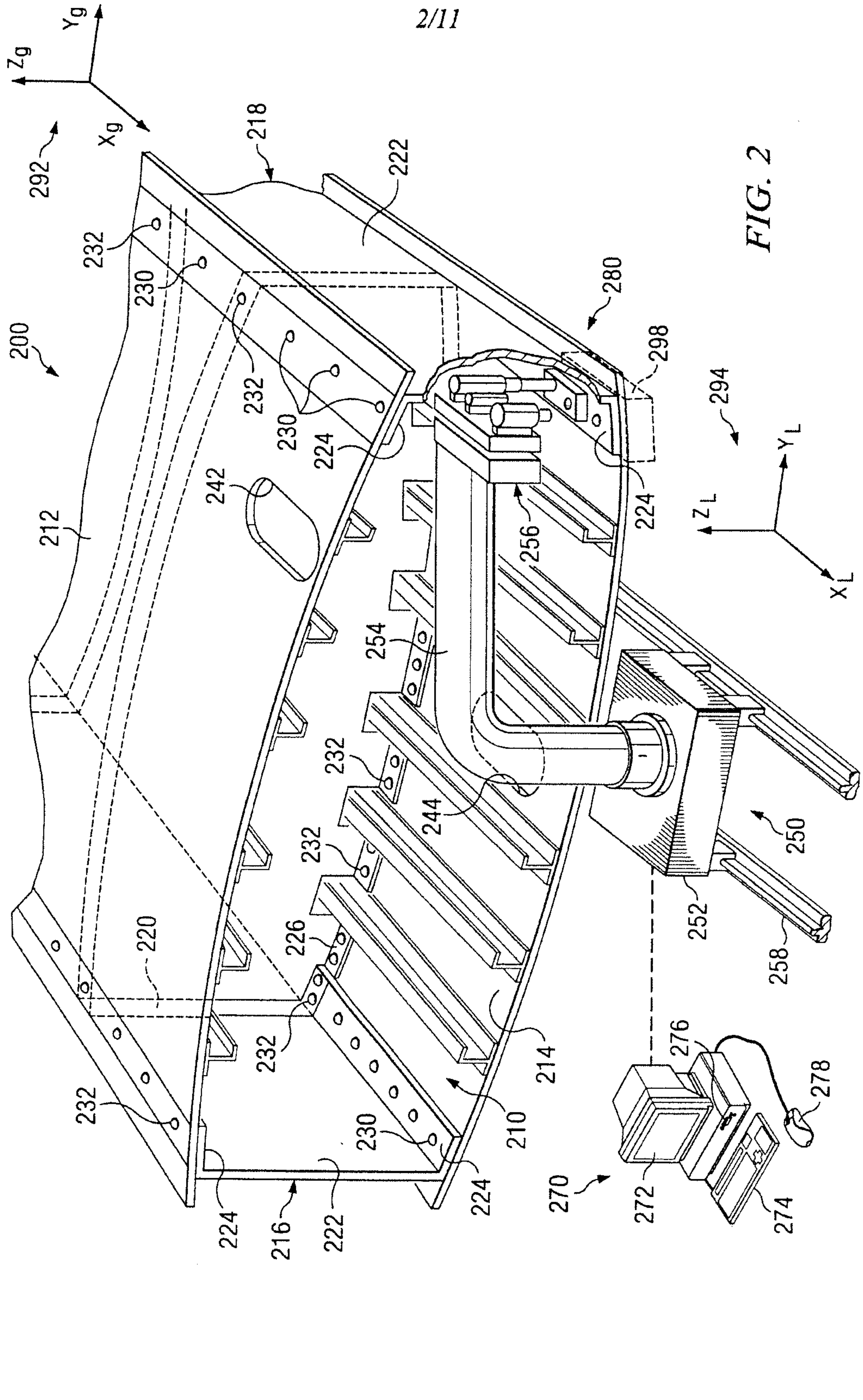

254
304
308
306
302

FIG. 3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212
292
218
222
232
230
242
224
280
298
294
256
254
244
250
252
258
220
226
214
210
216
270
272
274
276
278
X_g
Y_g
Z_g
X_L
Y_L
Z_L

FIG. 2

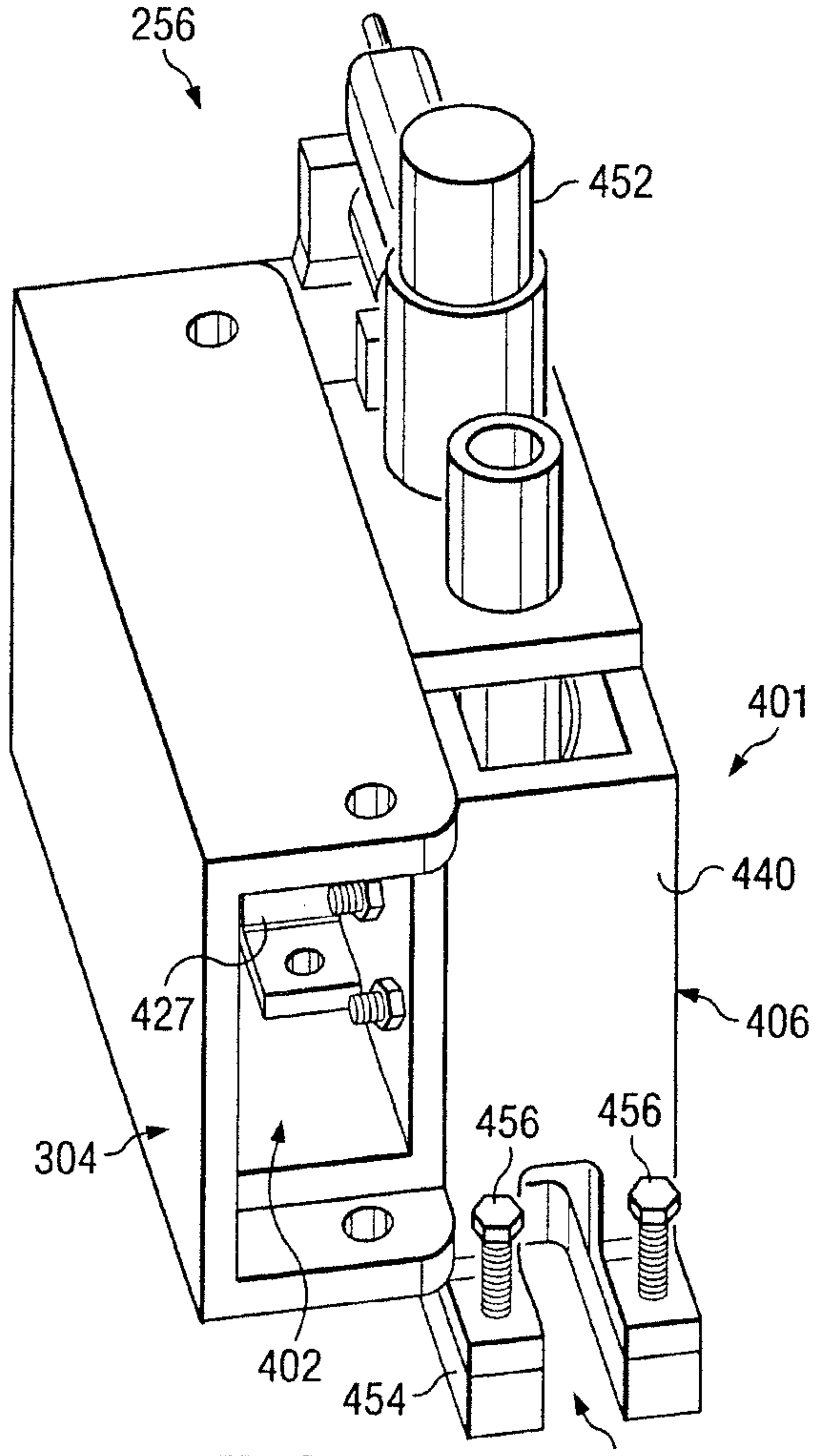
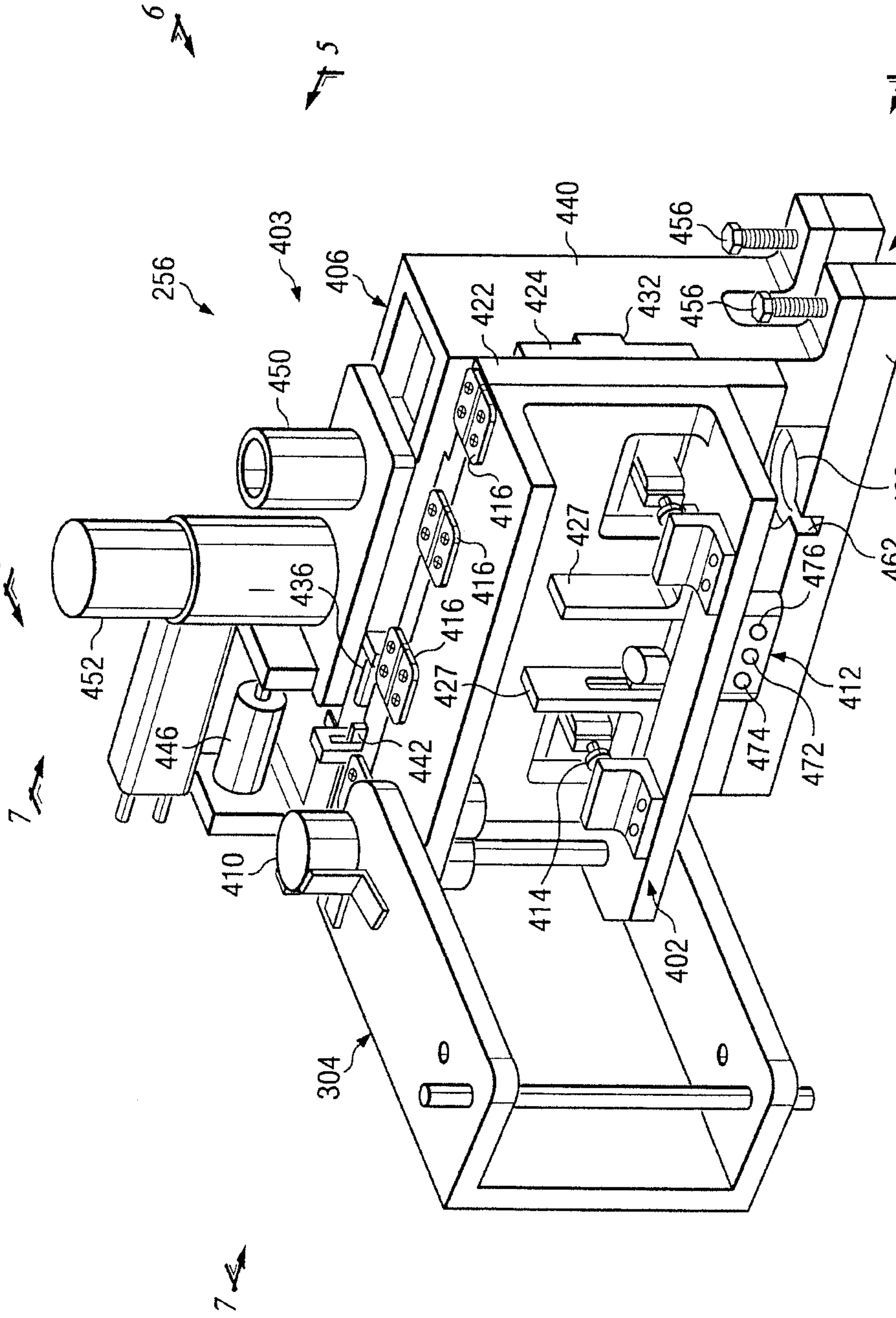


FIG. 4A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406
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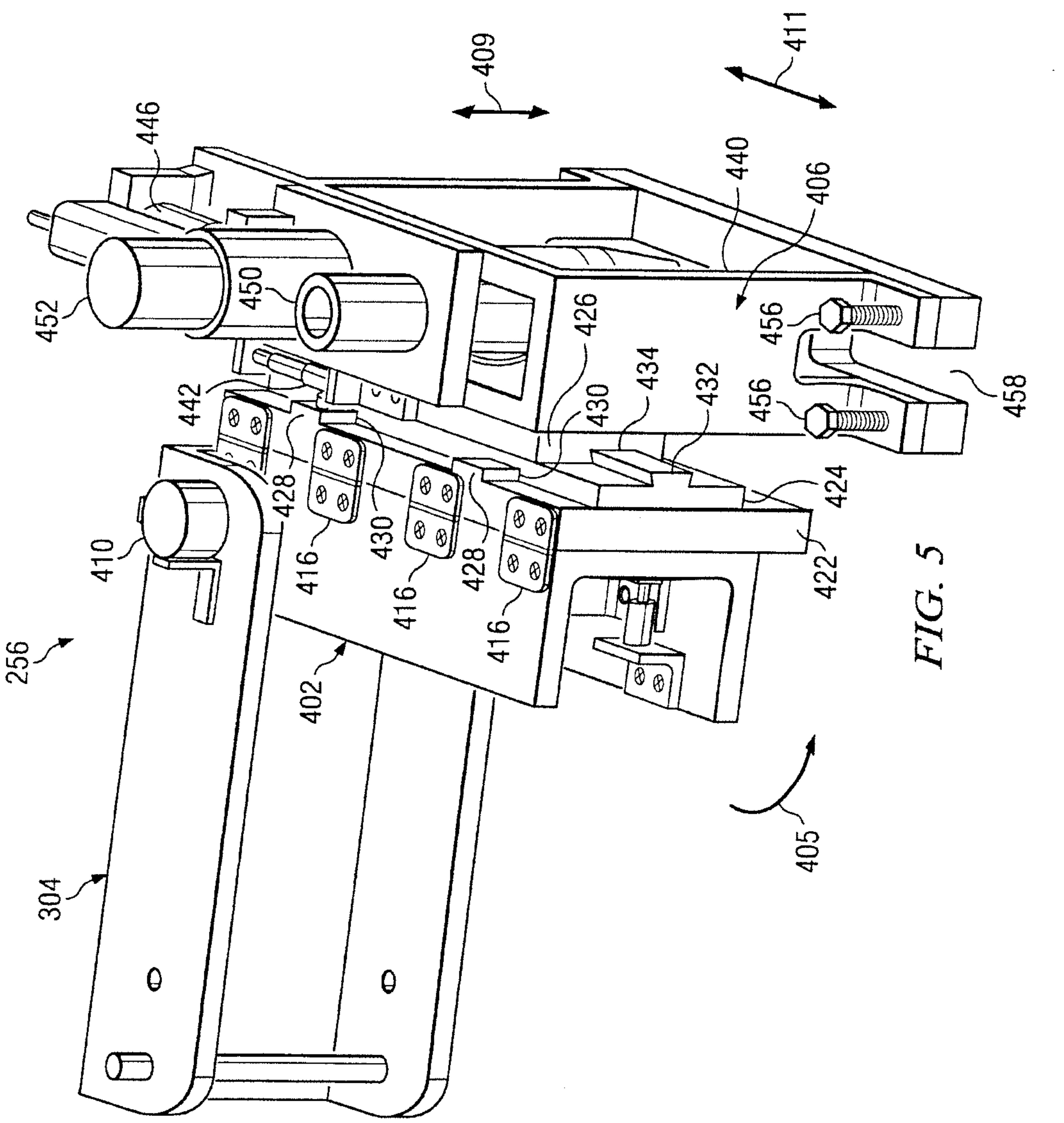
7
7

FIG. 4B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256
402
405
304

FIG. 5

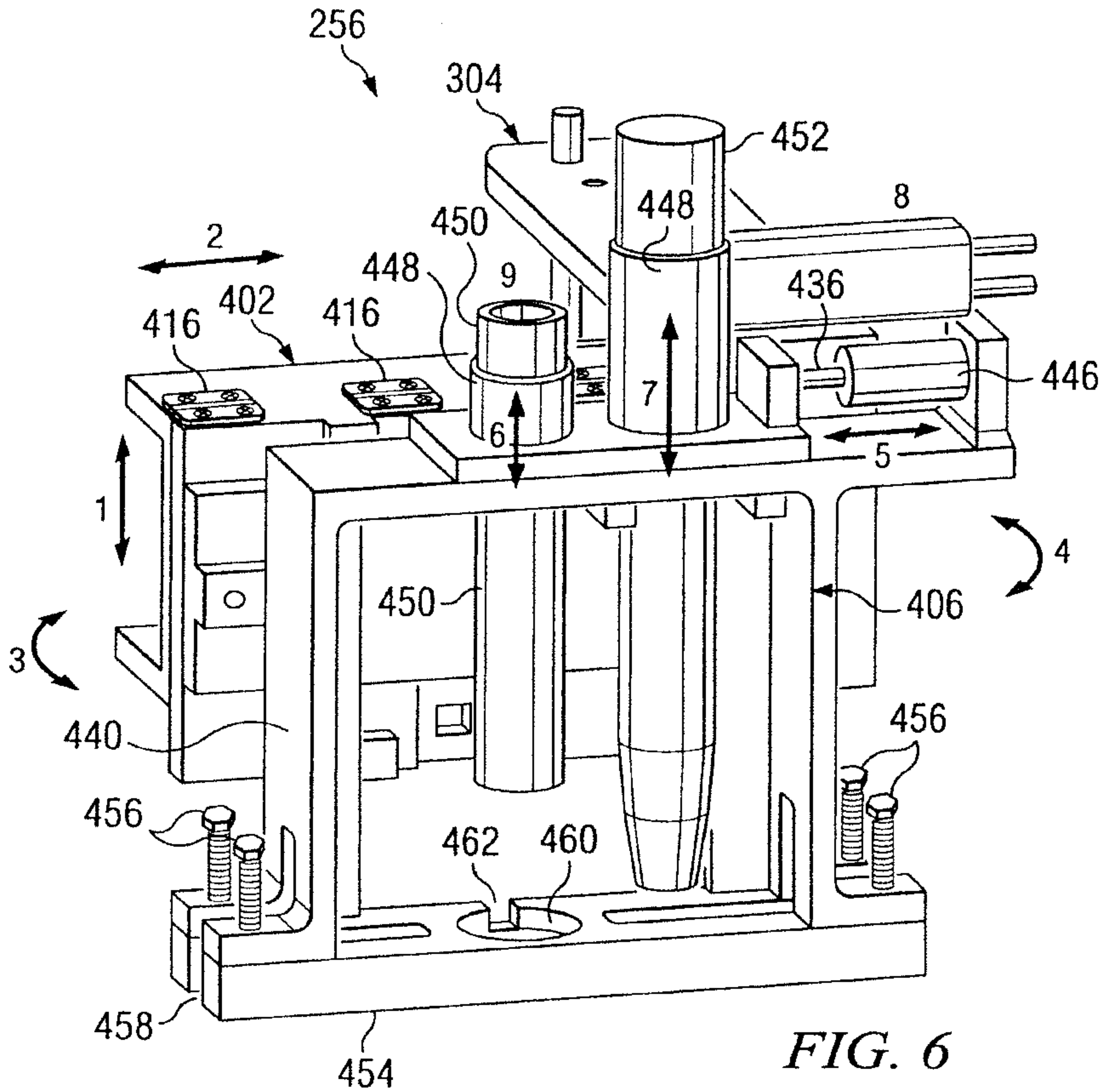
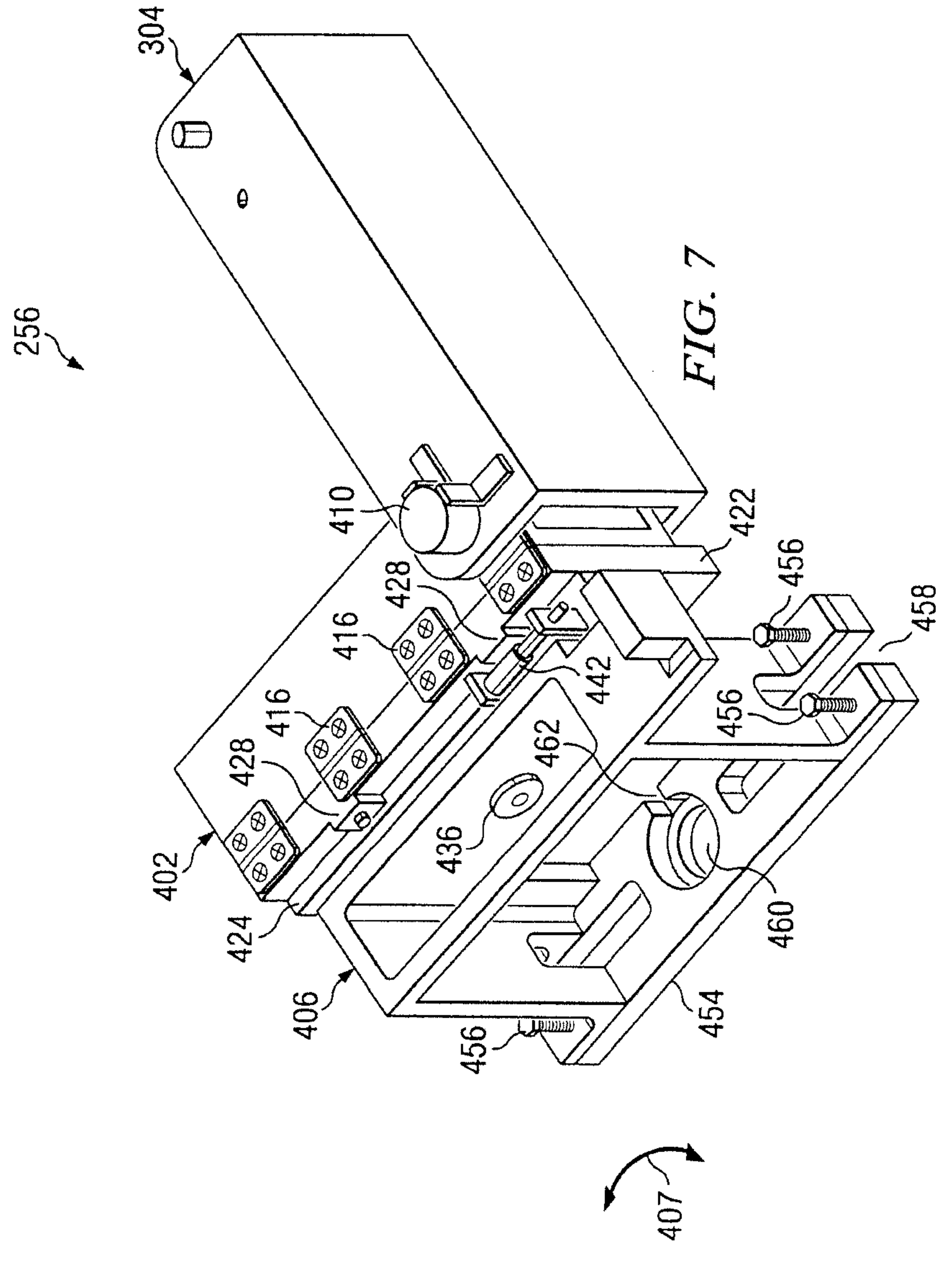


FIG. 6

CONTROLS	
1	UP/DOWN
2	LEFT/RIGHT
3	ROTATION ABOUT HINGES
4	ROLLING ROTATION
5	TOOL TRANSLATION
6	NUT DISPENSER UP/DOWN
7	NUT INSTALLER UP/DOWN
8	REMOTE TRIGGER SWITCH
9	NUT DELIVERY ACTIVATION


304
256
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422
428
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428
442
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436
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424
406
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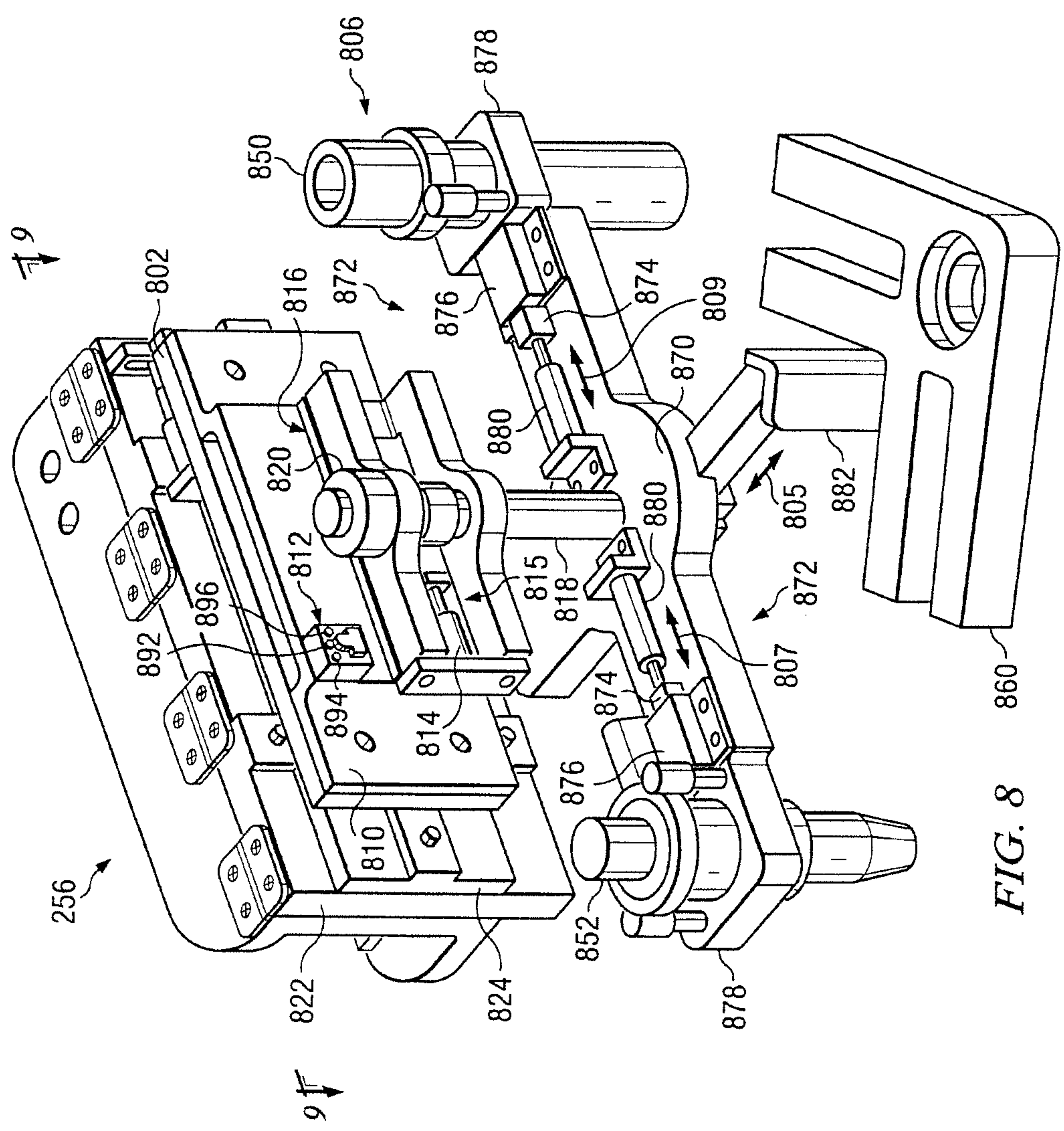
454
456
407

FIG. 7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850
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876
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820
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892
894
814
815
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805
882
872
807
874
876
810
852
878
822
824
860
9
9

FIG. 8

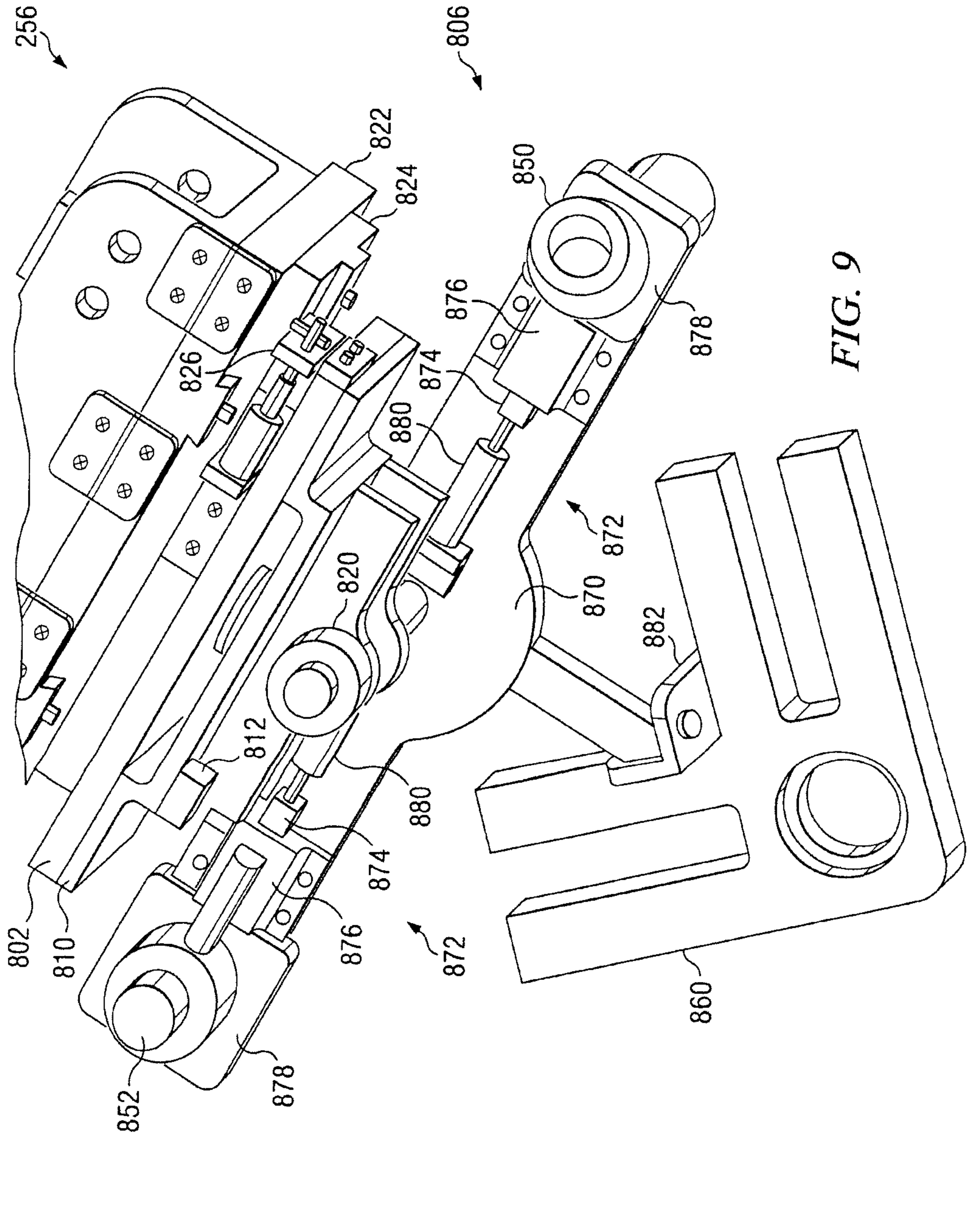
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FIG. 9

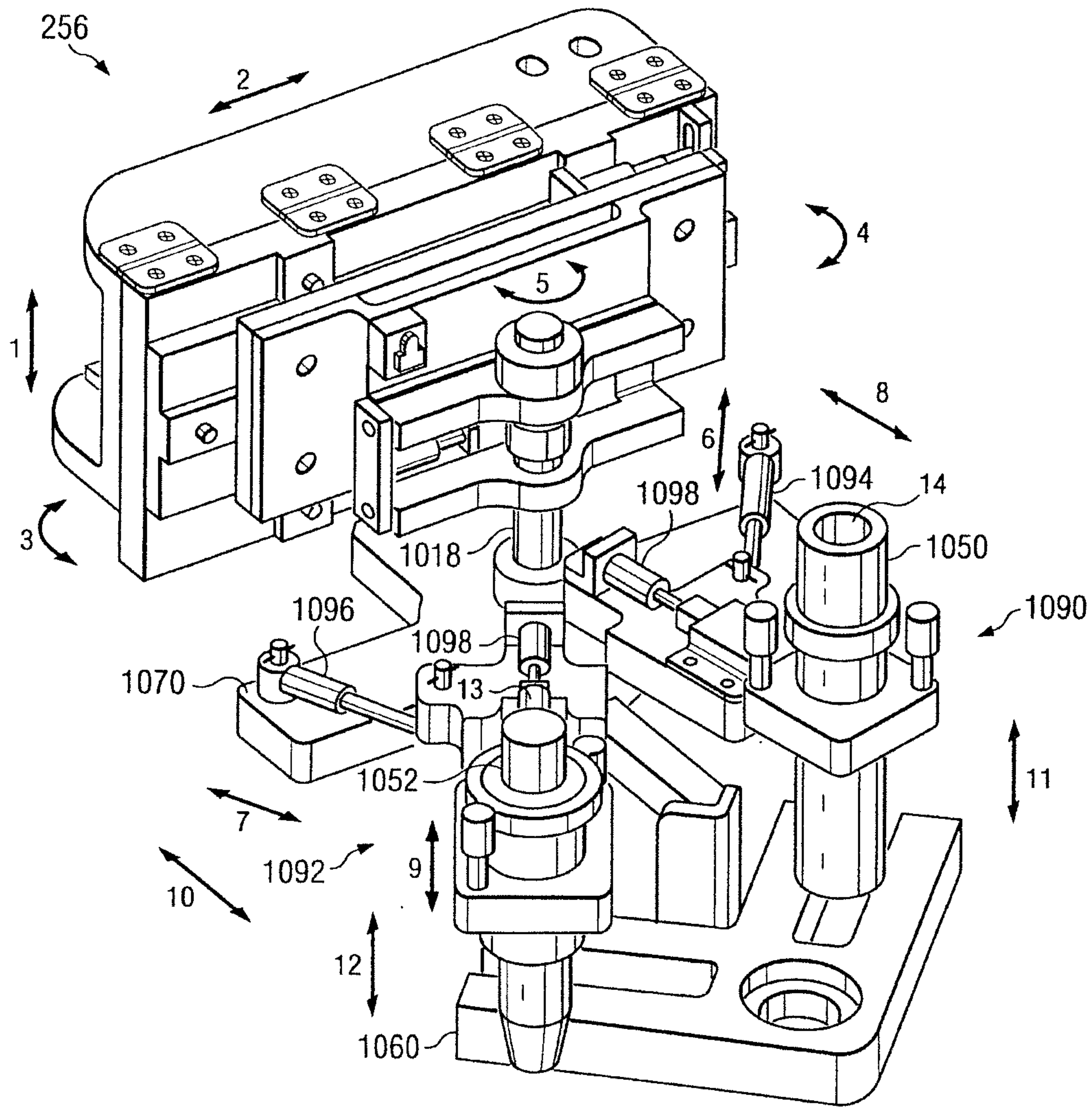


FIG. 10

CONTROLS	
1	UP/DOWN
2	LEFT/RIGHT
3	ROTATION ABOUT HINGES
4	ROLLING ROTATION
5	TOOL-PLATFORM ROTATION
6	NUT DISPENSER SWING
7	NUT INSTALLER SWING
8	NUT DISPENSER TRANSLATION
9	NUT INSTALLER TRANSLATION
10	STEEL FOOT TRANSLATION
11	NUT DISPENSER UP/DOWN
12	NUT INSTALLER UP/DOWN
13	REMOTE TRIGGER SWITCH
14	NUT DELIVERY ACTIVATION

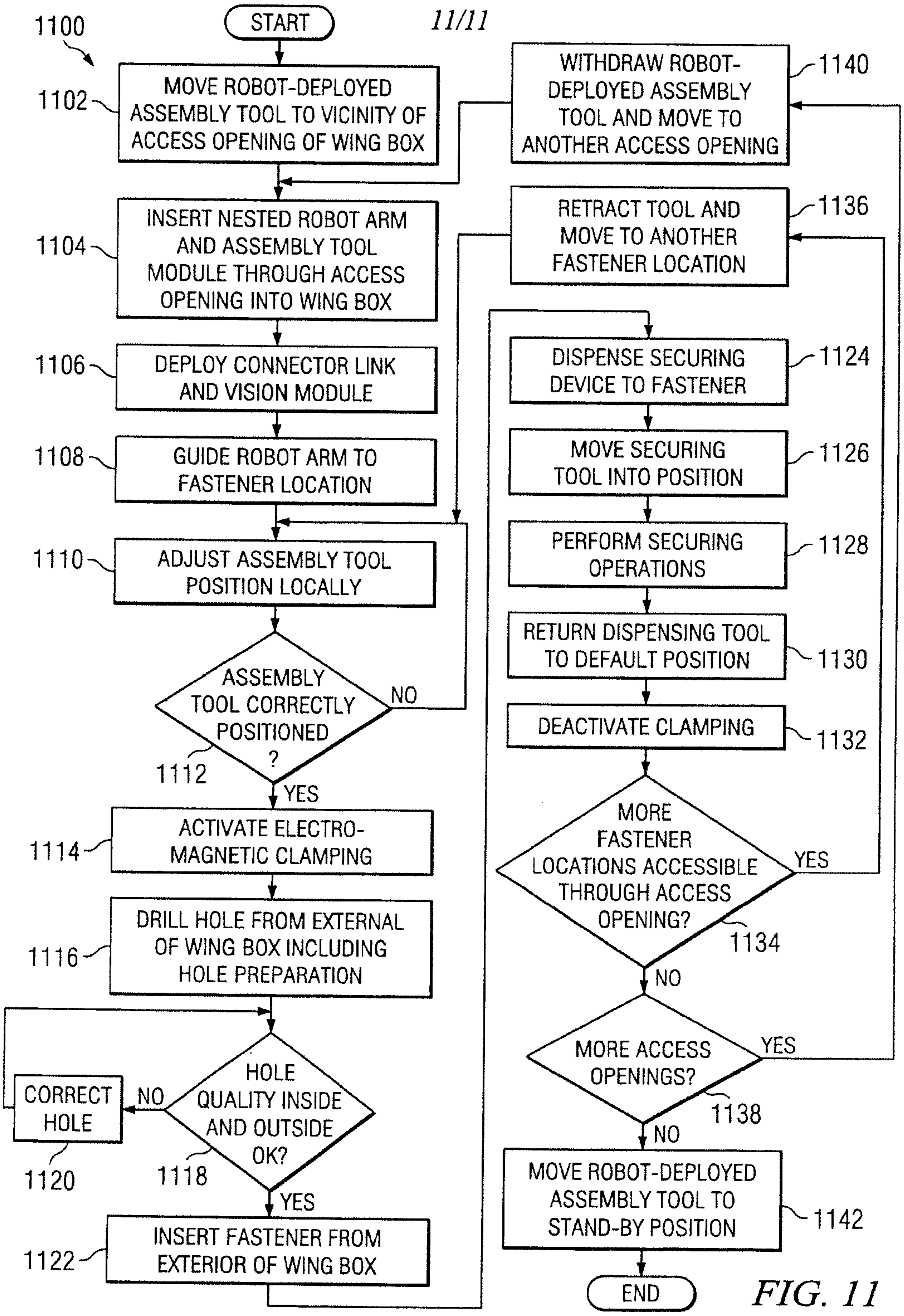
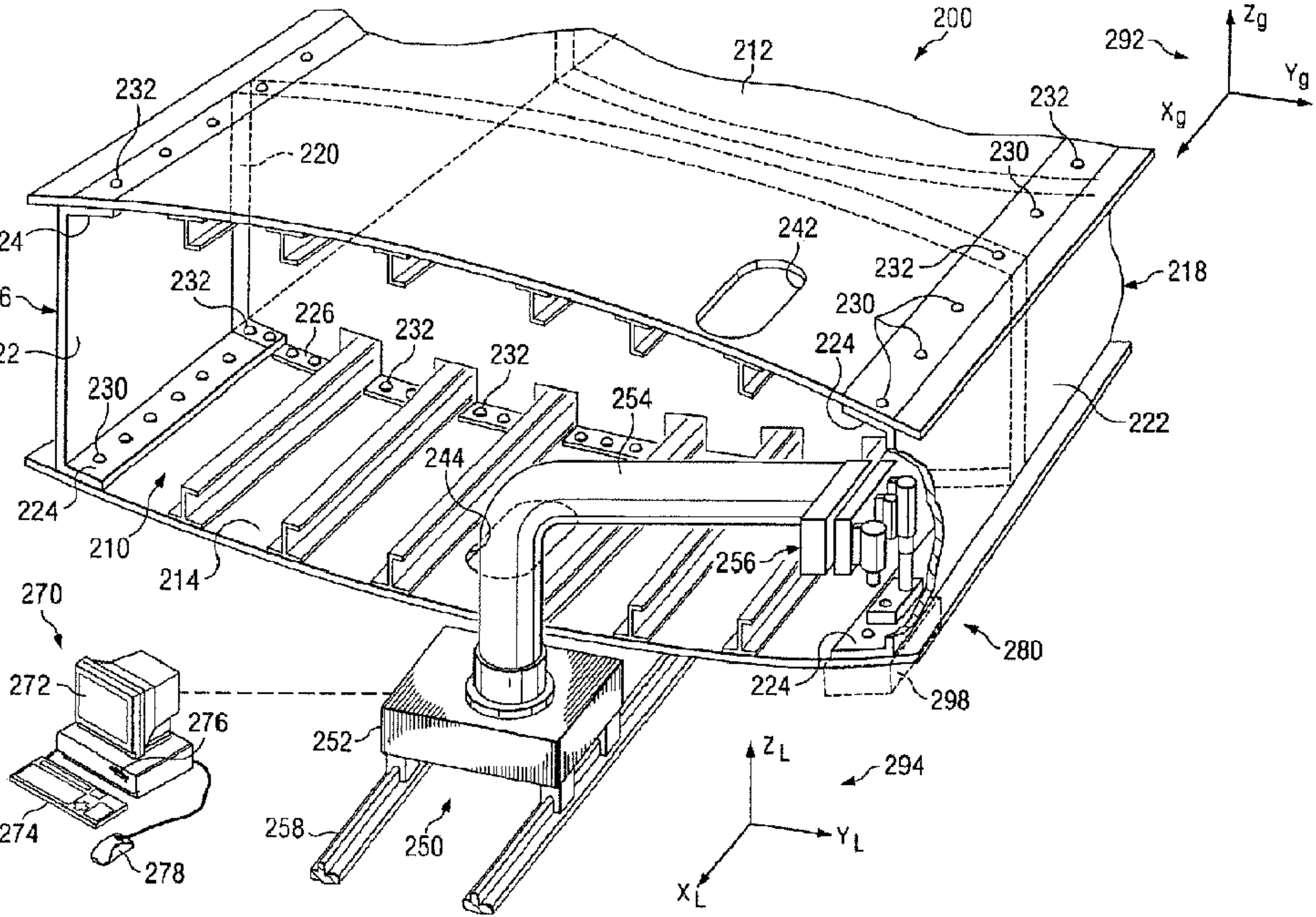

1100
START
1102
MOVE ROBOT-DEPLOYED ASSEMBLY TOOL TO VICINITY OF ACCESS OPENING OF WING BOX
1104
INSERT NESTED ROBOT ARM AND ASSEMBLY TOOL MODULE THROUGH ACCESS OPENING INTO WING BOX
1106
DEPLOY CONNECTOR LINK AND VISION MODULE
1108
GUIDE ROBOT ARM TO FASTENER LOCATION
1110
ADJUST ASSEMBLY TOOL POSITION LOCALLY
ASSEMBLY TOOL CORRECTLY POSITIONED ?
1112
NO
YES
1114
ACTIVATE ELECTRO-MAGNETIC CLAMPING
1116
DRILL HOLE FROM EXTERNAL OF WING BOX INCLUDING HOLE PREPARATION
HOLE QUALITY INSIDE AND OUTSIDE OK?
1118
NO
CORRECT HOLE
1120
YES
1122
INSERT FASTENER FROM EXTERIOR OF WING BOX
WITHDRAW ROBOT-DEPLOYED ASSEMBLY TOOL AND MOVE TO ANOTHER ACCESS OPENING
1140
RETRACT TOOL AND MOVE TO ANOTHER FASTENER LOCATION
1136
DISPENSE SECURING DEVICE TO FASTENER
1124
MOVE SECURING TOOL INTO POSITION
1126
PERFORM SECURING OPERATIONS
1128
RETURN DISPENSING TOOL TO DEFAULT POSITION
1130
DEACTIVATE CLAMPING
1132
MORE FASTENER LOCATIONS ACCESSIBLE THROUGH ACCESS OPENING?
1134
YES
NO
MORE ACCESS OPENINGS?
1138
YES
NO
MOVE ROBOT-DEPLOYED ASSEMBLY TOOL TO STAND-BY POSITION
1142
END

FIG. 11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252
274
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294
Z_L
Y_L
X_L