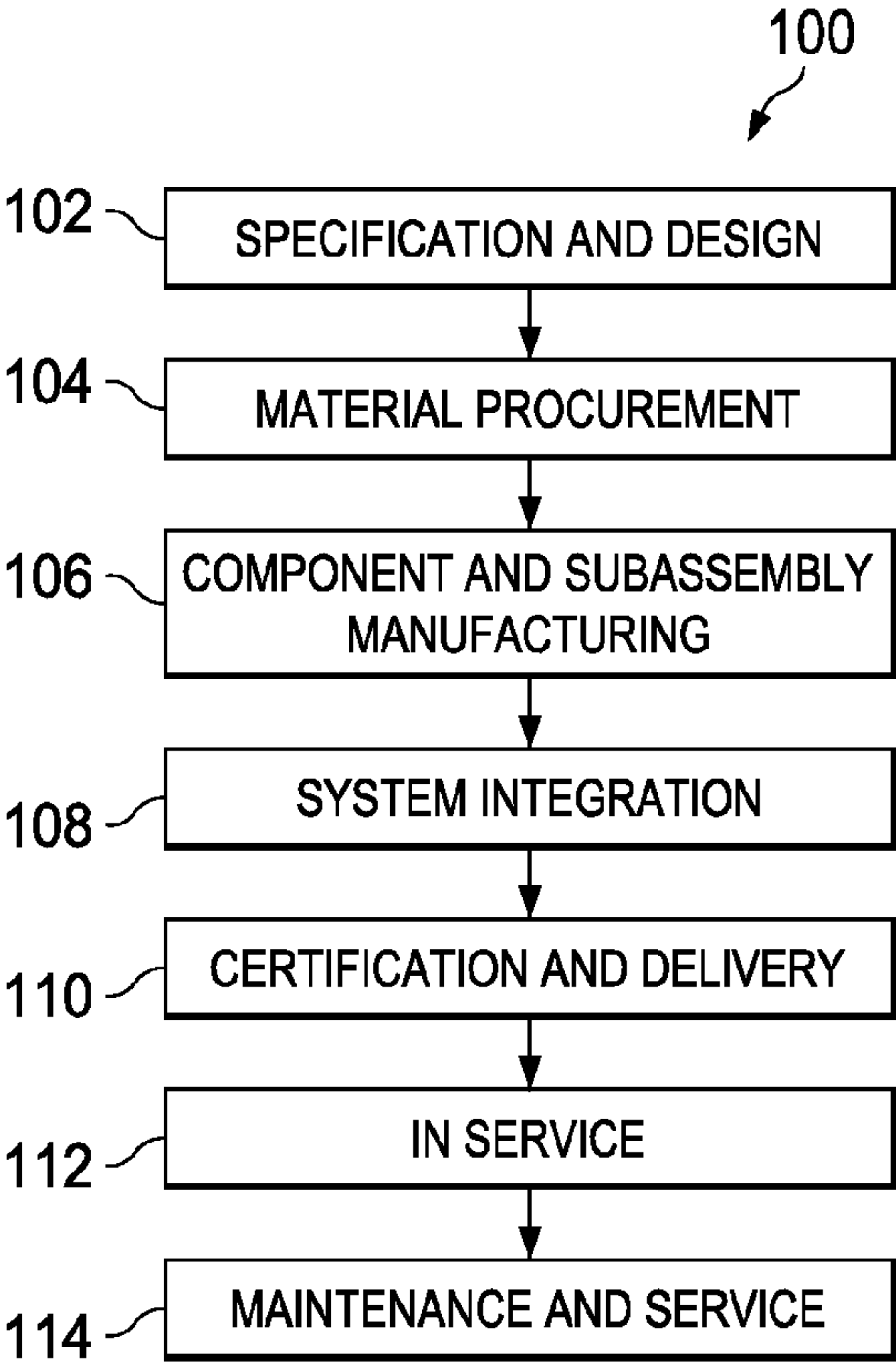




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(54) **Titre :** SYSTÈME D'ASSEMBLAGE ELECTROMAGNETIQUE DE CHENILLE
(54) **Title:** ELECTROMAGNETIC CRAWLER ASSEMBLY SYSTEM



(57) **Abrégé/Abstract:**
A method and apparatus for performing operations on a workpiece. A first frame in a frame system may be held on the workpiece by applying a vacuum to the first frame. A second frame in the frame system may be detached from the workpiece by applying a pressure to the second frame. The second frame may be moved to a location on the workpiece. The second frame may be attached to the workpiece by applying the vacuum to the second frame. An operation may be performed on the workpiece.

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12/838,616 19 July 2010 (19.07.2010) US(71) Applicant (for all designated States except US): **THE BOEING COMPANY** [US/US]; 100 North Riverside Plaza, Chicago, Illinois 60606-2016 (US).

(72) Inventors; and

(75) Inventors/Applicants (for US only): **SARH, Branko** [US/US]; 19542 Pompano Lane, Number 107, Huntington Beach, California 92648 (US). **AMIREHTESHAMI, David Hassan** [US/US]; 3111 Copa De Oro Drive, Los Alamitos, California 90720 (US).(74) Agents: **HALPERIN, Brett L** et al.; The Boeing Company, PO Box 2515, MC 110-SD54, Seal Beach, California 90740-1515 (US).

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[Continued on next page]

(54) Title: ELECTROMAGNETIC AND/OR VACUUM CRAWLER ASSEMBLY SYSTEM FOR MOVING AND FIXING A WORKING TOOLS ON ARCUATE SURFACE LIKE A FUSELAGE OF AN AIRPLANE

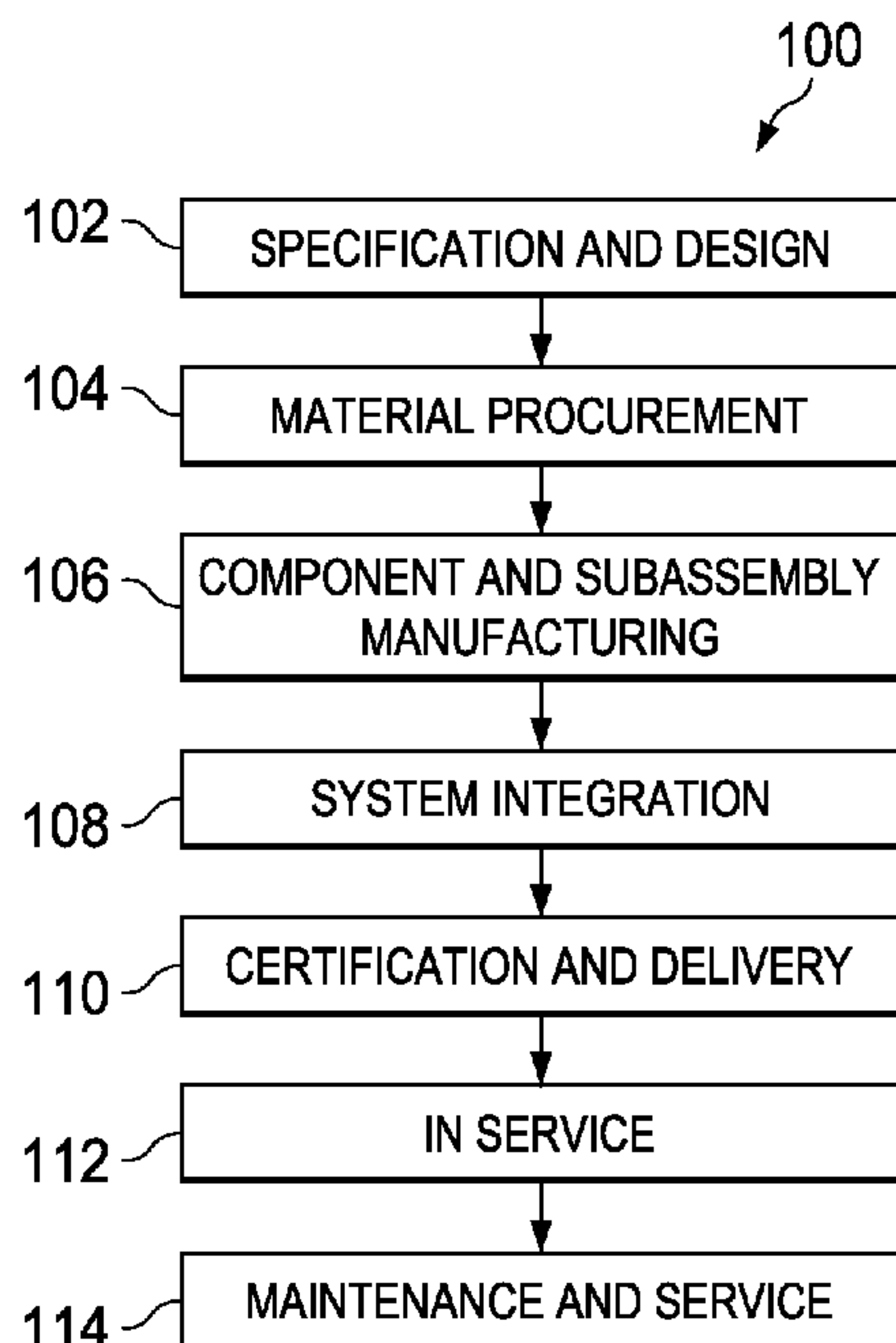


FIG. 1

(57) Abstract: A method and apparatus for performing operations on a workpiece. A first frame in a frame system may be held on the workpiece by applying a vacuum to the first frame. A second frame in the frame system may be detached from the workpiece by applying a pressure to the second frame. The second frame may be moved to a location on the workpiece. The second frame may be attached to the workpiece by applying the vacuum to the second frame. An operation may be performed on the workpiece.

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ELECTROMAGNETIC CRAWLER ASSEMBLY SYSTEM**BACKGROUND INFORMATION**5 **1. Field:**

 The present disclosure relates generally to manufacturing and, in particular, to a method and apparatus for attaching parts to each other. Still more particularly, the present disclosure relates to a method and apparatus for attaching
10 parts to each other using a fastening system.

2. Background:

 In manufacturing structures, different parts may be connected to each other to form the structures. Aircraft
15 structures, such as the wing and fuselage of an aircraft, may be manufactured by attaching parts to each other. For example, without limitation, panels may be placed onto ribs to form a fuselage. Panels also may be attached onto spars and ribs to form a wing for the aircraft.

20 The attachment of these panels and other parts to each other may be performed by operators or computer-controlled machines. With operators, two operators may be located opposite to each other on a workpiece, such as a panel and a rib. The operators may install clamping devices to hold the
25 parts together. Thereafter, a drill may be operated by one of the operators to create a hole. A rivet or other type of fastener may then be installed into the hole.

 This type of process may be time consuming and expensive. Large computer-controlled machines may be used to drill holes
30 and install fasteners to fasten the parts to each other.

 In some cases, however, the shape of the structure and/or the location of fasteners may prohibit the use of these machines. In these cases, operators may still perform the drilling and fastener installation operations. As a result,

depending on the design of the structure, the time and expense of installing fasteners may be greater than desired.

Therefore, it would be advantageous to have a method and apparatus that takes into account one or more of the issues
5 discussed above, as well as other possible issues.

SUMMARY

In one advantageous embodiment, an apparatus may comprise
10 a frame system and a controller. The frame system may have a first frame and a second frame in which the frame system may be configured to hold an end effector that is configured to perform a number of operations. The first frame and the second frame may be configured for attachment to a workpiece.
15 The controller may be configured to control attachment of the first frame and the second frame to the workpiece by applying a vacuum and a pressure during movement of the frame system.

In another advantageous embodiment, a crawler assembly system may comprise a frame system, a first number of suction
20 cups, a second number of suction cups, a controller, an electromagnetic unit, a vacuum and pressure unit, and an end effector. The frame system may be configured to hold an end effector that is configured to perform a number of operations on a workpiece. The frame system may comprise a first frame,
25 a second frame, a first number of legs, a second number of legs, and a movement system. The first frame and the second frame may be configured to move relative to each other on the workpiece. A first leg in a first portion of the first number of legs may be configured to rotate about a first axis in a
30 first direction. A second leg in a second portion of the first number of legs may be configured to rotate about the first axis in a second direction. Rotation of the first leg in the first direction and the second leg in the second direction about the first axis may cause rotation of the frame

system about a second axis that is substantially perpendicular to a surface of the workpiece. The movement system may be configured to move the first frame and the second frame relative to each other. The movement system may be configured to move the first number of legs and the second number of legs to conform to the surface of the workpiece while the end effector is performing the number of operations on the workpiece. The first number of suction cups may be connected to the first frame by the first number of legs. The first number of suction cups may be configured for attachment to the workpiece. A first portion of the first number of suction cups may be connected to the first portion of the first number of legs, and a second portion of the first number of suction cups may be connected to the second portion of the first number of legs. The second number of suction cups may be connected to the second frame by the second number of legs. The second number of suction cups may be configured for attachment to the workpiece. The controller may be configured to control an application of a vacuum and a pressure by the first number of suction cups and the second number of suction cups during movement of the frame system. Movement of the first portion of the first number of legs in the first direction and movement of the second portion of the first number of legs in the second direction, while the vacuum is applied to the first portion of the first number of suction cups and to the second portion of the second number of suction cups and the pressure is applied to the second number of suction cups, may cause the frame system to turn on the surface of the workpiece. The electromagnetic unit may be associated with the first frame. The electromagnetic unit may be configured to attract a magnetic material associated with the workpiece such that the electromagnetic unit may hold the first frame on the workpiece. A channel may extend through the electromagnetic unit and may be configured to receive an

end of the end effector and allow the end of the end effector to reach a surface of the workpiece. The vacuum and pressure unit may be connected to the first number of suction cups and the second number of suction cups. The vacuum and pressure
5 unit may be configured to apply at least one of the vacuum and the pressure to the first number of suction cups and the second number of suction cups. The end effector may comprise at least one of a drill unit, a fastener system, a sealant unit, and a vision system.

10 In yet another advantageous embodiment, a method may be provided for performing operations on a workpiece. A first frame in a frame system may be held on the workpiece by applying a vacuum to the first frame. A second frame in the frame system may be detached from the workpiece by applying a
15 pressure to the second frame. The second frame may be moved to a location on the workpiece. The second frame may be attached to the workpiece by applying the vacuum to the second frame. An operation may be performed on the workpiece.

In still yet another advantageous embodiment, a method
20 may be provided for performing operations on a workpiece. A crawler assembly system may be moved from a first location to a second location. The crawler assembly system may comprise a frame system, a first number of suction cups, a second number of suction cups, and a controller. The frame system may have
25 a first frame and a second frame in which the frame system may be configured to hold an end effector that may be configured to perform a number of operations. The first number of suction cups may be associated with the first frame by a number of legs. The first number of suction cups may be
30 configured for attachment to the workpiece. The second number of suction cups may be associated with the second frame. The second number of suction cups may be configured for attachment to the workpiece. The controller may be configured to control an application of a vacuum and a pressure by the first number

of suction cups and the second number of suction cups during movement of the frame system. Moving the crawler assembly system from the first location to the second location may comprise applying the vacuum to the first number of suction
5 cups and the pressure to the second number of suction cups, moving the second frame relative to the first frame while the first number of suction cups holds the first frame to the workpiece, applying the vacuum to the second number of suction cups after movement of the second frame, applying the pressure
10 to the first number of suction cups after the vacuum is applied to the second number of suction cups, moving the first frame relative to the second frame while the second number of suction cups holds the second frame to the workpiece, and repeating the steps of applying the vacuum to the first number
15 of suction cups and the pressure to the second number of suction cups, moving the second frame relative to the first frame while the first number of suction cups holds the first frame to the workpiece, applying the vacuum to the second number of suction cups after movement of the second frame,
20 applying the pressure to the first number of suction cups after the vacuum is applied to the second number of suction cups, and moving the first frame relative to the second frame while the second number of suction cups holds the second frame to the workpiece until the second location is reached. The
25 vacuum may be applied to a first portion of the first number of suction cups connected to a first portion of the number of legs and to a second portion of the first number of suction cups connected to a second portion of the number of legs. The pressure may be applied to the second number of suction cups.
30 A first leg in the first portion of the number of legs may be rotated in a first direction around a first axis. A second leg in the second portion of the first number of legs may be rotated in a second direction about the first axis. Rotation of the first leg and the second leg may cause rotation of the

frame system about a second axis that is substantially perpendicular to the surface of the workpiece. The number of operations may be performed at the location on the workpiece.

In another advantageous embodiment, an apparatus may
5 comprise a frame system having a first frame and a second frame in which the frame system is configured to hold an end effector that is configured to perform at least one operation in which the first frame is configured for attachment to a workpiece and in which the second frame is configured for attachment to the
10 workpiece; a controller configured to control attachment of the first frame and the second frame to the workpiece by applying a vacuum and a pressure during movement of the frame system; an electromagnetic unit associated with the first frame, the electromagnetic unit configured to attract a magnetic material
15 associated with the workpiece such that the electromagnetic unit engages the workpiece and holds the first frame on the workpiece; a channel extending through the electromagnetic unit configured to receive the end effector and allow the end effector to reach a surface of the workpiece when the
20 electromagnetic unit engages the workpiece; a first number of suction cups associated with the first frame in which the first number of suction cups is configured for attachment to the workpiece; and a second number of suction cups associated with the second frame in which the second number of suction cups is
25 configured for the attachment to the workpiece, wherein the controller is configured to control an application of the vacuum and the pressure by the first number of suction cups and the second number of suction cups during the movement of the frame system, the application of pressure including application of a
30 cushion of air configured to lift the first number of suction cups and the second number of suction cups off the surface of the workpiece so as to enable movement of the first frame and the second frame.

In another advantageous embodiment, a crawler assembly system may comprise an end effector comprising at least one of a drill unit, a fastener system, a sealant unit, and a vision system; a frame system configured to hold the end effector that is configured to perform a number of operations including at least one of drilling and fastening on a workpiece in which the frame system comprises: a first frame; a second frame in which the first frame and the second frame are configured to move relative to each other on the workpiece; a first number of legs in which a first leg in a first portion of the first number of legs is configured to rotate about a first axis in a first direction, in which a second leg in a second portion of the first number of legs is configured to rotate about the first axis in a second direction, and in which rotation of the first leg in the first direction and the second leg in the second direction about the first axis causes rotation of the frame system about a second axis that is substantially perpendicular to a surface of the workpiece; a second number of legs; and a movement system configured to move the first frame and the second frame relative to the each other and to move the first number of legs and the second number of legs to conform to the surface of the workpiece while the end effector is performing the number of operations on the workpiece; a first number of suction cups connected to the first frame by the first number of legs in which the first number of suction cups is configured for attachment to the workpiece and in which a first portion of the first number of suction cups is connected to the first portion of the first number of legs and a second portion of the first number of suction cups is connected to the second portion of the first number of legs; a second number of suction cups connected to the second frame by the second number of legs in which the second number of suction cups is configured for the attachment to the workpiece; a controller configured to control an

application of a vacuum and a pressure by the first number of suction cups and the second number of suction cups during movement of the frame system in which movement of the first portion of the first number of legs in the first direction and movement of the second portion of the first number of legs in the second direction, while the vacuum is applied to the first portion of the first number of suction cups and to a second portion of the second number of suction cups and the pressure is applied to the second number of suction cups, causes the frame system to turn on the surface of the workpiece, the application of pressure including application of a cushion of air configured to lift the first number of suction cups and the second number of suction cups off the surface of the workpiece so as to enable movement of the first frame and the second frame; an electromagnetic unit associated with the first frame in which the electromagnetic unit is configured to attract a magnetic material associated with the workpiece such that the electromagnetic unit holds the first frame on the workpiece and in which a channel extends through the electromagnetic unit and is configured to receive an end of the end effector and allow the end of the end effector to reach the surface of the workpiece, the electromagnet configured to stabilize the end effector when the electromagnet is engaged with the workpiece; a vacuum and pressure unit connected to the first number of suction cups and the second number of suction cups in which the vacuum and pressure unit is configured to apply at least one of the vacuum and the pressure to the first number of suction cups and the second number of suction cups; and a sensor system in communication with the controller, the sensor system configured to determine a location of the crawler assembly where the end effector performs the at least one operation.

In another advantageous embodiment, a crawler assembly system for performing an operation on a workpiece having a curved surface, may comprise an end effector configured to perform at least one of drilling or fastening; a first frame; a
5 second frame located inside of the first frame, the end effector attached to the second frame, the first frame is configured for attachment to a workpiece and the second frame configured for attachment to the workpiece; a controller configured to control attachment of the first frame and the second frame to the
10 workpiece by applying a vacuum and a pressure during movement of the first frame and the second frame; an electromagnetic unit associated with the second frame, the electromagnetic unit configured to attract a magnetic material associated with the workpiece such that the electromagnetic unit engages the
15 workpiece and holds the first frame on the workpiece, a channel extending through the electromagnetic unit configured to receive the end effector and allow the end effector to reach a surface of the workpiece when the electromagnetic unit engages the workpiece; a sensor system associated with the controller and
20 configured to determine a location of the crawler assembly where the end effector performs the at least one operation and to inspect the location; a first number of suction cups associated with the first frame in which the first number of suction cups is configured for attachment to the workpiece; and a second
25 number of suction cups associated with the second frame in which the second number of suction cups is configured for the attachment to the workpiece, wherein the controller is configured to control an application of the vacuum and the pressure by the first number of suction cups and the second
30 number of suction cups during the movement of the frame system, the application of pressure including application of a cushion of air configured to lift the first number of suction cups and the second number of suction cups off the surface of the workpiece so as to enable movement of the first frame and the
35 second frame.

In another advantageous embodiment, a method for performing operations on a workpiece, may comprise holding a first frame in a frame system on the workpiece by applying a vacuum to the first frame, wherein the frame system is part of a crawler assembly system, the crawler assembly system comprises an end effector associated with the frame system and configured to perform an operation on the workpiece, the workpiece is a portion of a structure of a vehicle or building, and wherein the workpiece includes magnetic material; detaching a second frame in the frame system from the workpiece by applying a pressure to the second frame; moving the second frame to a location on the workpiece; attaching the second frame to the workpiece by applying the vacuum to the second frame; attracting the magnetic material of the workpiece with an electromagnetic unit associated with the first frame to aid in the attaching of the first frame to the workpiece, wherein a channel extending through the electromagnetic unit receives the end effector and allows the end effector to reach a surface of the workpiece when the electromagnetic unit attracts the magnetic material of the workpiece; and performing the operation on the workpiece.

In another advantageous embodiment, a method for performing operations on a workpiece, may comprise moving a crawler assembly system from a first location on the workpiece to a second location on the workpiece, wherein the workpiece is a portion of a structure of a vehicle or building, the workpiece includes magnetic material, wherein the crawler assembly system comprises: a frame system having a first frame and a second frame in which the frame system is configured to hold an end

effector that is configured to perform a number of operations; a first number of suction cups associated with the first frame by a number of legs in which the first number of suction cups is configured for attachment to the workpiece; a second number of suction cups associated with the second frame in which the second number of suction cups is configured for attachment to the workpiece; and a controller configured to control an application of a vacuum and a pressure by the first number of suction cups and the second number of suction cups during movement of the frame system, and wherein the step of moving the crawler assembly system from the first location on the workpiece to the second location on the workpiece comprises: applying the vacuum to the first number of suction cups and the pressure to the second number of suction cups; moving the second frame relative to the first frame while the first number of suction cups holds the first frame to the workpiece; applying the vacuum to the second number of suction cups after movement of the second frame; applying the pressure to the first number of suction cups after the vacuum is applied to the second number of suction cups; moving the first frame relative to the second frame while the second number of suction cups holds the second frame to the workpiece; repeating the steps of applying the vacuum to the first number of suction cups and the pressure to the second number of suction cups; moving the second frame relative to the first frame while the first number of suction cups holds the first frame to the workpiece; applying the vacuum to the second number of suction cups after the movement of the second frame; applying the pressure to the first number of

suction cups after the vacuum is applied to the second number of suction cups; and moving the first frame relative to the second frame while the second number of suction cups holds the second frame to the workpiece until the second location on the

5 workpiece is reached; applying the vacuum to a first portion of the first number of suction cups connected to a first portion of the number of legs and to a second portion of the first number of suction cups connected to a second portion of the number of legs; applying the pressure to the second number of suction

10 cups; rotating a first leg in the first portion of the number of legs in a first direction around a first axis; rotating a second leg in the second portion of the number of legs in a second direction about the first axis in which rotation of the first leg and the second leg causes rotation of the frame system about

15 a second axis that is substantially perpendicular to a surface of the workpiece; attracting the magnetic material of the workpiece with an electromagnetic unit associated with the first frame to aid in the attaching of the first frame to the workpiece, wherein a channel extending through the

20 electromagnetic unit receives the end effector and allows the end effector to reach the surface of the workpiece when the electromagnetic unit attracts the magnetic material of the workpiece; and performing the number of operations at the second location on the workpiece.

In another advantageous embodiment, an apparatus may comprise a frame system for holding an end effector that is configured to perform a number of operations, the frame system having a first frame and a second frame; a first number of
5 suction cups for attachment to a workpiece, associated with the first frame; a second number of suction cups for attachment to the workpiece, associated with the second frame; and a controller configured to control attachment of the first frame and the second frame to the workpiece by applying a vacuum and a
10 pressure during movement of the frame system, wherein the controller is configured to control an application of the vacuum and the pressure by the first number of suction cups and the second number of suction cups during the movement of the frame system, and wherein the application of the pressure comprises
15 providing a cushion of air to lift a respective suction cup off of the workpiece.

In another advantageous embodiment, a method for performing operations on a workpiece may comprise holding a first frame in a frame system on the workpiece by applying a
20 vacuum to the first frame; detaching a second frame in the frame system from the workpiece by applying a pressure to the second frame, wherein applying the pressure comprises providing a cushion of air to lift the second frame off of the workpiece; moving the second frame to a location on the workpiece;
25 attaching the second frame to the workpiece by applying the vacuum to the second frame; and performing an operation on the workpiece.

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

BRIEF DESCRIPTION OF THE DRAWINGS

The novel features believed characteristic of the advantageous embodiments are set forth in the appended claims.

5 The advantageous embodiments, 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 an advantageous embodiment of the present disclosure when read in conjunction with the accompanying
10 drawings, wherein:

Figure 1 is an illustration of an aircraft manufacturing and service method in accordance with an advantageous embodiment;

Figure 2 is an illustration of an aircraft in which an
15 advantageous embodiment may be implemented;

Figure 3 is an illustration of a manufacturing environment in accordance with an advantageous embodiment;

Figure 4 is an illustration of a manufacturing environment in accordance with an advantageous embodiment;

20 **Figure 5** is an illustration of a crawler assembly system in accordance with an advantageous embodiment;

Figure 6 is an illustration of a bottom view of a crawler assembly structure in accordance with an advantageous embodiment;

Figure 7 is an illustration of a front view of a crawler assembly system in accordance with an advantageous embodiment;

Figure 8 is an illustration of a cross-sectional side view of a portion of a crawler assembly system in accordance with an advantageous embodiment;

Figure 9 is an illustration of a cross-sectional side view of a portion of a crawler assembly system in accordance with an advantageous embodiment;

Figure 10 is an illustration of a crawler assembly system in accordance with an advantageous embodiment;

Figure 11 is an illustration of a back view of a crawler assembly system placed on a workpiece in accordance with an advantageous embodiment;

Figure 12 is an illustration of a crawler assembly system on a workpiece in accordance with an advantageous embodiment;

Figure 13 is an illustration of a crawler assembly system on a workpiece in accordance with an advantageous embodiment;

Figure 14 is an illustration of a crawler assembly system on a workpiece in accordance with an advantageous embodiment;

Figure 15 is an illustration of a crawler assembly system on a workpiece in accordance with an advantageous embodiment;

Figure 16 is an illustration of a crawler assembly system in accordance with an advantageous embodiment;

Figure 17 is an illustration of a flowchart of a process for performing operations on a workpiece in accordance with an advantageous embodiment;

Figure 18 is an illustration of a flowchart of a process for moving a crawler assembly system in accordance with an advantageous embodiment; and

Figure 19 is an illustration of a flowchart of a process for adjusting the legs of a crawler assembly system in accordance with an advantageous embodiment.

5

DETAILED DESCRIPTION

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 aircraft **200** as shown in **Figure 2**. Turning first to **Figure 1**, an illustration of an aircraft manufacturing and service method is depicted in accordance with an advantageous embodiment. During pre-production, aircraft manufacturing and service method **100** may include specification and design **102** of aircraft **200** in **Figure 2** and material procurement **104**.

During production, component and subassembly manufacturing **106** and system integration **108** of aircraft **200** in **Figure 2** takes place. Thereafter, aircraft **200** in **Figure 2** may go through certification and delivery **110** in order to be placed in service **112**. While in service **112** by a customer, aircraft **200** in **Figure 2** may be scheduled for routine maintenance and service **114**, which may include modification, reconfiguration, refurbishment, and other maintenance or service.

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. In these examples, the operator may be 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, without limitation, any number of vendors, subcontractors, and suppliers; and an operator may be an airline, leasing company, military entity, service organization, and so on.

With reference now to **Figure 2**, an illustration of an aircraft is depicted in which an advantageous embodiment may be implemented. In this example, aircraft **200** may be produced by aircraft manufacturing and service method **100** in **Figure 1**
5 and may include airframe **202** with a plurality of systems **204** and interior **206**. Examples of systems **204** may 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. Although an
10 aerospace example is shown, different advantageous embodiments may be applied to other industries, such as the automotive industry.

Apparatus and methods embodied herein may be employed during at least one of the stages of aircraft manufacturing
15 and service method **100** in **Figure 1**. As used herein, the phrase "at least one of", when used with a list of items, means that different combinations of one or more of the listed items may be used and only one of each item in the list may be needed. For example, "at least one of item A, item B, and
20 item C" may include, for example, without limitation, item A or item A and item B. This example also may include item A, item B, and item C or item B and item C.

In one illustrative example, components or subassemblies produced in component and subassembly manufacturing **106** in
25 **Figure 1** may be fabricated or manufactured in a manner similar to components or subassemblies produced while aircraft **200** is in service **112** in **Figure 1**. As yet another example, a number of apparatus embodiments, method
embodiments, or a combination thereof may be utilized during
30 production stages, such as component and subassembly manufacturing **106** and system integration **108** in **Figure 1**. A number, when referring to items, means one or more items. For example, a number of apparatus embodiments may be one or more apparatus embodiments. A number of apparatus embodiments,

method embodiments, or a combination thereof may be utilized while aircraft **200** is in service **112** and/or during maintenance and service **114** in **Figure 1**. The use of a number of the different advantageous embodiments may substantially expedite
5 the assembly of and/or reduce the cost of aircraft **200**.

The different advantageous embodiments recognize and take into account a number of considerations. For example, without limitation, the different advantageous embodiments recognize and take into account that smaller robotic machines may be
10 used to reach locations on or within a structure that larger robotic machines may not be able to reach. The different advantageous embodiments recognize and take into account that in locations in which larger robotic machines cannot be used, smaller robotic machines may be employed.

15 For example, without limitation, some robotic machines may move on the structure being assembled. These robotic machines may use a rail system for movement. A rail system may be attached to the structure.

As one illustrative example, without limitation, when
20 skin panels are clamped to a frame for a fuselage, a rail system may be attached to the structure. The robotic machine may then move along the rails and perform operations to fasten the skin panels to the ribs. These robotic machines may drill holes and insert fasteners to attach skin panels to the ribs
25 of the structure.

The different advantageous embodiments recognize that the use of robotic machines with rail systems may be cumbersome and more time consuming than desired. The rails may need to be repositioned from location to location. This repositioning
30 may require removing the robotic machine, removing the rail, reinstalling the rail in the new location, and then placing the robotic machine back onto the rail.

The different advantageous embodiments also recognize and take into account that, in some cases, the robotic machines

may have legs with suction cups. Those suction cups may engage and disengage themselves from the panels and move to different locations to perform operations. The movement of the legs along with the engagement and disengagement of the
5 suction cups may occur in a manner that moves the machine.

The different advantageous embodiments recognize and take into account that these currently used machines may have a first frame and a second frame. The frames may move relative to each other. The legs on both frames may have suction cups
10 that attach to the surface of the structure when a vacuum is applied.

When the robotic machine is ready to move to another location, the suction cups for the legs on one frame may be disengaged. Those legs may then be raised away from the
15 surface of the structure. The first frame may then move relative to the second frame. Thereafter, the legs may be extended back onto the surface. A vacuum may be applied to the suction cups to reengage the suction cups to the surface. Thereafter, the suction cups or the legs on the second frame
20 may be disengaged from the surface of the structure. Those legs may then be retracted. The second frame may move relative to the first frame. Thereafter, the legs may be re-extended and the suction cups may be engaged to the surface.

However, the different advantageous embodiments recognize
25 and take into account that with these types of frames that move in parallel to each other, the systems may be more complex, heavier, and slower than desired. Further, the different advantageous embodiments also recognize that with the use of these types of systems, additional safety features
30 may be needed. These safety features may include additional straps or lines to secure the robotic machine in case the vacuum generated by the suction cups does not provide the needed amount of vacuum to maintain attachment to the structure.

The different advantageous embodiments recognize and take into account that these types of systems may require more time to set up and operate than desired.

Thus, the different advantageous embodiments provide a
5 method and apparatus for performing operations on a structure. In one advantageous embodiment, an apparatus may comprise a frame system, a first number of suction cups, a second number of suction cups, and a controller. The frame system may have a first frame and a second frame in which the frame system may
10 be configured to hold an end effector that is configured to perform a number of operations. The first frame and the second frame may be configured for attachment to a workpiece. The controller may be configured to control attachment of the first frame and the second frame to the workpiece by applying
15 a vacuum and a pressure during movement of the frame system.

With reference now to **Figure 3**, an illustration of a manufacturing environment is depicted in accordance with an advantageous embodiment. In this illustrative example, manufacturing environment **300** may be an example of an
20 environment that may be used to manufacture structures for aircraft **302**. Aircraft **302** may be an example of one implementation for aircraft **200** in **Figure 2**. Aircraft **302** may have fuselage **304** and nose **306**.

In this depicted example, crawler assembly system **308** may
25 be used to manufacture structures for aircraft **302**. Crawler assembly system **308** may be an example of a robotic machine in this illustrative example. Crawler assembly system **308** may be used during at least one of component and subassembly manufacturing **106**, system integration **108**, maintenance and
30 service **114**, and/or other suitable phases during aircraft manufacturing and service method **100** in **Figure 1**.

As depicted in this example, crawler assembly system **308** may be placed on surface **310** of fuselage **304**. As one illustrative example, crawler assembly system **308** may be used

to install fasteners onto surface **310** of fuselage **304**.
Additionally, crawler assembly system **308** may be used to
perform a number of other operations to manufacture structures
for aircraft **302**.

5 With reference now to **Figure 4**, an illustration of a
manufacturing environment is depicted in accordance with an
advantageous embodiment. Manufacturing environment **400** is an
example of an environment that may be used to manufacture
structures for aircraft **200** in **Figure 2**. Further,
10 manufacturing environment **300** in **Figure 3** may be an example of
one implementation for manufacturing environment **400** in **Figure**
4.

 In these illustrative examples, manufacturing environment
400 may be used during at least one of component and
15 subassembly manufacturing **106**, system integration **108**,
maintenance and service **114**, and other suitable phases during
aircraft manufacturing and service method **100** in **Figure 1**.

 In these illustrative examples, crawler assembly system
402 may perform number of operations **404** on workpiece **406**. In
20 these illustrative examples, workpiece **406** may be a structure
or a portion of a structure for aircraft **200** in **Figure 2**. Of
course, workpiece **406** may be for other types of objects other
than aircraft **200** in **Figure 2**. For example, without
limitation, workpiece **406** may be for an automobile, a truck, a
25 building, a spacecraft, a missile, a ship, a submarine, a dam,
a bridge, and/or some other suitable type of object.

 In this illustrative example, crawler assembly system **402**
may comprise frame system **408**, controller **410**, electromagnetic
unit **412**, vacuum and pressure unit **414**, end effector **416**,
30 sensor system **418**, and other suitable components. When
electromagnetic unit **412** is present, crawler assembly system
402 may be referred to as an electromagnetic crawler assembly
system.

Frame system **408** may comprise first frame **420**, second frame **422**, movement system **424**, first number of legs **426**, second number of legs **428**, first number of suction cups **430**, second number of suction cups **432**, and/or other suitable components. Frame system **408** may be configured to hold end effector **416**.

In these illustrative examples, first frame **420** and second frame **422** may move relative to each other. Movement system **424** may cause first frame **420** and second frame **422** to move relative to each other. In these examples, movement system **424** may comprise number of motors **434**.

First number of suction cups **430** may be associated with first frame **420** and may be configured for attachment to workpiece **406**. Second number of suction cups **432** may be associated with second frame **422**. Second number of suction cups **432** may be configured for attachment to workpiece **406**.

In these illustrative examples, a first component may be considered to be associated with a second component by being secured to the second component, bonded to the second component, fastened to the second component, and/or connected to the second component in some other suitable manner. The first component also may be connected to the second component through using a third component. The first component may also be considered to be associated with the second component by being formed as part of and/or an extension of the second component.

In these examples, first number of suction cups **430** may be associated with first frame **420** using first number of legs **426**. Second number of suction cups **432** may be associated with second frame **422** using second number of legs **428**.

In these illustrative examples, the attachment of first number of suction cups **430** and second number of suction cups **432** may be a removable attachment. The attachment may be caused by vacuum **436** applied by vacuum and pressure unit **414**.

Vacuum **436** may be applied to first number of suction cups **430** through first number of legs **426** and to second number of suction cups **432** through second number of legs **428** in these examples. Vacuum **436** may cause first number of suction cups **430** and second number of suction cups **432** to be attached to workpiece **406**.

In these illustrative examples, vacuum **436** may be applied through at least a portion of first number of suction cups **430** and second number of suction cups **432** to attach portion **438** of first number of suction cups **430** and/or portion **439** of second number of suction cups **432** to surface **440** of workpiece **406**. In these examples, first number of suction cups **430** and second number of suction cups **432** may have a number of different shapes and/or sizes.

In these illustrative examples, first number of legs **426** and second number of legs **428** may be moveable relative to surface **440** of workpiece **406**. First number of legs **426** and second number of legs **428** may be moveable to conform to surface **440**. For example, without limitation, surface **440** may be curved about one or more different axes (not shown). First number of legs **426** and/or second number of legs **428** may be moved relative to surface **440** to allow first number of suction cups **430** and/or second number of suction cups **432** to contact surface **440**.

In this manner, vacuum **436** may be applied to attach first number of suction cups **430** and/or second number of suction cups **432** to surface **440** of workpiece **406**. The positioning or movement of first number of legs **426** and/or second number of legs **428** may be performed using movement system **424**.

In these illustrative examples, movement of crawler assembly system **402** may be accomplished in any number of different ways. In one illustrative example, first number of suction cups **430** and second number of suction cups **432** may be

attached to surface **440** of workpiece **406** during the performance of number of operations **404**.

In these illustrative examples, end effector **416** may perform number of operations **404** under the control of controller **410**. End effector **416** may comprise at least one of drill unit **441**, fastener system **443**, sealant unit **445**, vision system **447**, and/or other suitable devices. End effector **416** may be a device that may be moved by crawler assembly system **402** to different locations on workpiece **406** to perform number of operations **404**.

In these depicted examples, number of operations **404** may be performed at location **444** within area **442** of workpiece **406**. Area **442** may be an area within which end effector **416** may be moved by crawler assembly system **402** without moving frame system **408**. After number of operations **404** have been performed, crawler assembly system **402** may be moved to location **448**.

In these illustrative examples, end effector **416** may be stabilized using electromagnetic unit **412**. Electromagnetic unit **412** may be associated with first frame **420**. Electromagnetic unit **412** may engage magnetic material **446** on workpiece **406** to provide better attachment of crawler assembly system **402** to workpiece **406** during performance of number of operations **404**. This provides attachment in addition to applying vacuum **436** to first number of suction cups **430** and second number of suction cups **432**.

When moving from location **444** to location **448**, vacuum **436** may be applied to first number of suction cups **430** and pressure **450** may be applied to second number of suction cups **432**. Pressure **450** may provide force **452** to lift second frame **422** away from surface **440** of workpiece **406**.

In these illustrative examples, first number of suction cups **430** and second number of suction cups **432** may also be configured to apply vacuum **436** and/or pressure **450**. Suction

cups of various geometries may be used to implement first number of suction cups **430** and second number of suction cups **432**. Examples of suction cups that may be used include, for example, without limitation, suction cups available from Piab
5 USA, Inc.

Second frame **422** may be moved relative to first frame **420** by movement system **424** while pressure **450** is applied to second number of suction cups **432** and vacuum **436** is applied to first number of suction cups **430**. After movement of second frame
10 **422** has completed, vacuum **436** may be applied to second number of suction cups **432**.

Additionally, pressure **450** may be applied to first number of suction cups **430** while vacuum **436** is applied to second number of suction cups **432**. Then, first frame **420** may be
15 moved relative to second frame **422** while vacuum **436** is applied to second number of suction cups **432** and pressure **450** is applied to first number of suction cups **430**. This sequence of steps may be performed to move workpiece **406** from location **444** to location **448**.

20 Additionally, in some advantageous embodiments, first frame **420** and second frame **422** may move relative to each other to move frame system **408** from location **444** to location **448**, while end effector **416** performs number of operations **404**. In this manner, pauses in the performance of number of operations
25 **404** for movement of crawler assembly system **402** may be reduced and/or avoided.

Further, electromagnetic unit **412** may provide force **454** to hold first frame **420** on workpiece **406**, while second frame **422** moves relative to first frame **420**. Additionally,
30 electromagnetic unit **412** may provide an additional mechanism to hold crawler assembly system **402** on workpiece **406** in case first number of suction cups **430** and second number of suction cups **432** are unable to hold frame system **408** on workpiece **406**.

In these illustrative examples, controller **410** may comprise a computer, a processor unit, an application specific integrated circuit, or some other suitable device that controls the operation of crawler assembly system **402**.

5 Controller **410** may be configured to control attachment of first frame **420** and second frame **422** to workpiece **406** by applying vacuum **436** and pressure **450** during movement of frame system **408**. Controller **410** may store locations and/or operations to be performed on workpiece **406** in the form of
10 program code **456**. Program code **456** may be run to perform number of operations **404** on workpiece **406**.

Sensor system **418**, in these illustrative examples, may be used to identify the location of crawler assembly system **402** on workpiece **406**. Further, sensor system **418** may be used to
15 position end effector **416** relative to workpiece **406**. Sensor system **418** also may be used to perform inspections on number of operations **404**. In these illustrative examples, sensor system **418** may comprise, for example, without limitation, infrared sensors, cameras, ultrasonic sensors, and/or other
20 suitable types of sensors.

The illustration of manufacturing environment **400** is not meant to imply physical architectural limitations to the manner in which different advantageous embodiments may be implemented. Other components in addition to and/or in place
25 of the ones illustrated may be used. Some components may be unnecessary in some advantageous embodiments. Also, the blocks are presented to illustrate some functional components. One or more of these blocks may be combined and/or divided into different blocks when implemented in different
30 advantageous embodiments.

For example, in some advantageous embodiments, crawler assembly systems in addition to crawler assembly system **402** may be present to perform operations on workpiece **406**. In still other advantageous embodiments, crawler assembly system

402 may comprise a number of additional end effectors in addition to end effector **416**. Also, additional electromagnetic units in addition to electromagnetic unit **412** may be present.

5 In these illustrative examples, first leg **458** and second leg **462** in first number of legs **426** may be configured to rotate about axis **460**. The rotation of first leg **458** and/or second leg **462** about axis **460** may cause electromagnetic unit **412** to rotate about axis **460**. In this manner, the positioning
10 of electromagnetic unit **412** may be performed for different types of surfaces on workpiece **406**.

 With reference now to **Figure 5**, an illustration of a crawler assembly system is depicted in accordance with an advantageous embodiment. In this illustrative example,
15 crawler assembly system **500** may be an example of one implementation for crawler assembly system **308** in **Figure 3** and/or crawler assembly system **402** in **Figure 4**.

 Crawler assembly system **500** may include frame system **502**, electromagnetic unit **504**, vacuum and pressure unit **506**, end
20 effector **508**, sensor system **510**, and controller **512**. In this illustrative example, frame system **502** may comprise first frame **514**, second frame **516**, movement system **518**, first number of legs **520**, second number of legs **522**, first number of suction cups **524**, and second number of suction cups **526**.

25 In this depicted example, second frame **516** may include portion **511** and portion **513**. Portion **511** and portion **513** may be attached to each other to form second frame **516**. Further, first frame **514** may be associated with portion **513** of second frame **516**.

30 First frame **514** and second frame **516** may move relative to each other using movement system **518**. Movement system **518** may include motor **528** in this illustrative example. Additionally, movement system **518** may include motors **552**, **553**, **554**, **555**, **556**, **557**, **558**, **559**, **560**, and **561**. Movement system **518** may be

used to move at least a portion of first number of legs **520** relative to at least a first portion of second number of legs **522**.

In this depicted example, first number of legs **520** and
5 first number of suction cups **524** may be associated with first frame **514**. First number of legs **520** may include leg **530** and leg **531**. First number of suction cups **524** may include suction cup **532** and suction cup **533** attached to leg **530** and leg **531**, respectively. First number of suction cups **524** may be
10 configured to be attached to a surface of a workpiece (not shown), such as workpiece **406** in **Figure 4**.

Second number of legs **522** and second number of suction cups **526** may be associated with second frame **516**. Second number of legs **522** may include legs **534**, **535**, **536**, **537**, **538**,
15 **539**, **540**, and **541**. Second number of suction cups **526** may include suction cups **542**, **543**, **544**, **545**, **546**, **547**, and **548** attached to legs **534**, **535**, **536**, **537**, **538**, **539**, and **541**, respectively, and another suction cup (not shown) attached to leg **540**. Second number of suction cups **526** also may be
20 configured to be attached to the surface of the workpiece.

In this illustrative example, first number of legs **520** and second number of legs **522** may be moveable. Movement of first number of legs **520** and/or second number of legs **522** may be provided by movement system **518**.

For example, without limitation, motor **552** and motor **553**
25 may move leg **530** and leg **531**, respectively, vertically in the direction of arrow **549**. Further, motors **554**, **555**, **556**, **557**, **558**, **559**, **560**, and **561** may be associated with legs **534**, **535**, **536**, **537**, **538**, **539**, **540**, and **541**, respectively. Each of these
30 motors may be configured to move a corresponding leg vertically in the direction of arrow **549**. Legs within first number of legs **520** and/or second number of legs **522** may be moved to different positions by movement system **518**.

With this type of movement for first number of legs **520** and second number of legs **522**, first number of legs **520** and second number of legs **522** may be capable of substantially conforming to the surface of the workpiece when the surface is a curved surface. For example, legs within first number of legs **520** and/or second number of legs **522** may be moved such that first number of suction cups **524** and second number of suction cups **526** may all contact the curved surface of the workpiece.

The attachment of first number of suction cups **524** and second number of suction cups **526** to the workpiece may be performed using vacuum and pressure unit **506**. Vacuum and pressure unit **506** may include lines that connect vacuum and pressure unit **506** to first number of legs **520** and second number of legs **522**.

For example, without limitation, vacuum and pressure unit **506** may include lines **562**, **563**, **564**, **565**, **566**, **567**, **568**, and **569** that connect to legs **534**, **535**, **536**, **537**, **538**, **539**, **540**, and **541**, respectively. Further, vacuum and pressure unit **506** may include line **570** and line **571** that connect to leg **530** and leg **531**, respectively. Vacuum and pressure unit **506** may apply a vacuum and/or pressure to these legs through these lines.

Vacuum and pressure unit **506** may generate a vacuum such that at least a portion of first number of suction cups **524** and/or second number of suction cups **526** may attach to a surface of the workpiece. In particular, vacuum and pressure unit **506** may generate a vacuum through at least a portion of second number of legs **522** and/or first number of legs **520** such that at least a portion of first number of suction cups **524** and/or second number of suction cups **526** may attach to a surface of the workpiece. In other words, vacuum and pressure unit **506** may evacuate the air within at least a portion of first number of suction cups **524** and/or second number of

suction cups **526** to generate the vacuum that allows attachment to the surface of the workpiece.

In this illustrative example, first frame **514** may move relative to second frame **516** in the direction of arrow **549** and the direction of arrow **525** using vacuum and pressure unit **506** and movement system **518**. For example, without limitation, vacuum and pressure unit **506** may apply a vacuum to first number of suction cups **524**. The vacuum may cause first number of suction cups **524** to attach to the surface of the workpiece.

Vacuum and pressure unit **506** may also apply pressure to second number of suction cups **526**. In other words, vacuum and pressure unit **506** may pressurize second number of suction cups **526** instead of applying a vacuum to second number of suction cups **526**. This pressurization may provide a force to lift second number of suction cups **526** off the surface of the workpiece. Further, the pressurization of second number of suction cups **526** may be provided by a cushion of air in this illustrative example. In this manner, second frame **516** may be lifted off of the surface of the workpiece by the pressure applied by vacuum and pressure unit **506**.

With second frame **516** lifted off the surface of the workpiece, motor **528** may be operated to move second frame **516** relative to first frame **514**. Second frame **516** may be moved in the direction of arrow **525** while first frame **514** remains attached to the surface of the workpiece by first number of suction cups **524**.

When second frame **516** has been moved to the desired location, vacuum and pressure unit **506** may apply a vacuum to second number of suction cups **526** to attach second number of suction cups **526** to the surface of the workpiece. In these illustrative examples, crawler assembly system **500** may be moved over the surface of the workpiece by moving either first frame **514** or second frame **516** first.

In these depicted examples, each suction cup in first number of suction cups **524** and second number of suction cups **526** may have a flexibility that may allow each suction cup to attach to a curved surface. Further, this flexibility may
5 allow at least a portion of first number of suction cups **524** and/or second number of suction cups **526** to attach to a surface at an angle relative to a surface to which another portion of first number of suction cups **524** and/or second number of suction cups **526** is attached. As one illustrative
10 example, one portion of second number of suction cups **526** may be attached to a portion of a surface at a first angle and another portion of second number of suction cups **526** may be attached to another portion of the surface at a second angle.

Additionally, crawler assembly system **500** may also have
15 motor **550** and motor **551** associated with first frame **514**. Motor **550** and motor **551** may be electric motors, air motors, air cylinders, and/or some other suitable type of motor. Motor **550** and motor **551** may be used to rotate at least one of leg **530** and leg **531**. For example, without limitation, leg **530**
20 may be rotated in a first direction about axis **590**, and leg **531** may be rotated in a second direction about axis **590**. Rotation of leg **530** and leg **531**, while a vacuum is applied to suction cup **532** and suction cup **533**, may cause rotation of frame system **502** about axis **592**. Rotation of frame system **502**
25 about axis **592** may cause crawler assembly system **500** to turn on the surface of a workpiece.

Additionally, motor **550** and motor **551** may be used to rotate leg **530** and leg **531** such that suction cup **532** and suction cup **533** may contact a curved surface for the
30 workpiece.

In this illustrative example, electromagnetic unit **504** may provide additional attachment of crawler assembly system **500** to the workpiece. For example, without limitation, electromagnetic unit **504** may provide additional attachment of

crawler assembly system **500** to the workpiece if any of the suction cups in first number of suction cups **524** or second number of suction cups **526** do not attach to the workpiece as desired.

5 Additionally, end effector **508** may be used to perform a number of operations on the workpiece. In this illustrative example, end effector **508** may include drill unit **580** and fastener system **581**. Drill unit **580** may be used to perform drilling operations, and fastener system **581** may be used to
10 perform fastening operations. These operations may be performed while first frame **514** is attached to the workpiece. Second frame **516** may be attached to the workpiece or may be moving towards a desired location while the operations are performed by end effector **508**.

15 In this illustrative example, sensor system **510** may be used to generate information about the surface of the workpiece on which the operations are to be performed. For example, without limitation, sensor system **510** may include camera **582** in this depicted example. Camera **582** may be used
20 to generate image information used to identify the location at which the operations are to be performed. Further, the image information may also be used for positioning drill unit **580** and/or fastener system **581** for performing the operations.

 As depicted in this illustrative example, controller **512**
25 may be associated with first frame **514**. Controller **512** may take the form of computer system **584** in this depicted example. Computer system **584** may be used to control crawler assembly system **500**. For example, without limitation, computer system **584** may be used to control the movement of crawler assembly
30 system **500** by movement system **518**, the positioning of end effector **508**, the types of operations performed by end effector **508**, and/or other suitable operations.

 In these illustrative examples, controller **512** may be operated manually and/or automatically. For example, in some

cases, controller **512** may run program code to control crawler assembly system **500**. In other examples, controller **512** may be operated by a human operator.

With reference now to **Figure 6**, an illustration of a bottom view of a crawler assembly structure is depicted in accordance with an advantageous embodiment. In this illustrative example, suction cup **600** in second number of suction cups **526** for crawler assembly system **500** in **Figure 5** may be seen. Suction cup **600** may be associated with leg **540** in second number of legs **522** in **Figure 5**.

With reference now to **Figure 7**, an illustration of a front view of a crawler assembly system is depicted in accordance with an advantageous embodiment. In this illustrative example, crawler assembly system **500** may be seen from the front of first frame **514**. As depicted, crawler assembly system **500** may be placed on workpiece **700**. In particular, suction cups **546**, **547**, **600**, and **548** may be seen attached to surface **702** of workpiece **700**.

With reference now to **Figure 8**, an illustration of a cross-sectional side view of a portion of a crawler assembly system is depicted in accordance with an advantageous embodiment. As depicted in this example, crawler assembly system **500** may use motor **550** to rotate leg **530** about axis **590** substantially perpendicular to axis **592**. Leg **530** may be rotated about axis **590** such that center line **802** for leg **530** may be rotated about plus or minus five degrees away from axis **592** in the direction of arrow **800**.

With reference now to **Figure 9**, an illustration of a cross-sectional side view of a portion of a crawler assembly system is depicted in accordance with an advantageous embodiment. In this illustrative example, center line **802** for leg **530** has been rotated to position **900**. As depicted, position **900** may be about plus five degrees away from axis

592. The rotation of leg **530** may be caused by the operation of motor **550** in this illustrative example.

Additionally, leg **531** in **Figure 5** may also be rotated to a position away from axis **592** in a direction opposite to the rotation of leg **530** in this illustrative example. Rotation of these two legs in opposite directions may cause frame system **502** to rotate about axis **592**. In this manner, crawler assembly system **500** may be turned using motor **550** and motor **551** in **Figure 5** to rotate leg **530** and leg **531**, respectively.

With reference now to **Figure 10**, an illustration of a crawler assembly system is depicted in accordance with an advantageous embodiment. In this illustrative example, crawler assembly system **500** may have a different configuration as compared to the configuration for crawler assembly system **500** in **Figure 5**.

As depicted in this example, portion **511** of second frame **516** may be removed. Only portion **513** of second frame **516** may be present for crawler assembly system **500**. Removal of portion **511** may reduce the size and/or weight of crawler assembly system **500**. This reduction in size and/or weight may allow crawler assembly system **500** to move to a greater number of locations and be in a greater number of positions as compared to when portion **511** is present for crawler assembly system **500**.

With reference now to **Figure 11**, an illustration of a back view of a crawler assembly system placed on a workpiece is depicted in accordance with an advantageous embodiment. In this illustrative example, a back view of crawler assembly system **500** may be illustrated taken along lines **11-11** in **Figure 10**. As depicted, crawler assembly system **500** may be shown from the view of controller **512**.

In this illustrative example, crawler assembly system **500** may be placed on workpiece **1100**. Workpiece **1100** may have curved surface **1102** in this illustrative example. Legs **538**,

539, 540, and 541 may be moved such that suction cup 546, 547, 600, and 548 are in contact with curved surface 1102.

In this illustrative example, suction cup 532 and suction cup 533 may not be in contact with curved surface 1102 such that first frame 514 may be moved along axis 1104. For example, without limitation, vacuum and pressure unit 506 may apply pressure to suction cup 532 and suction cup 533. In other words, the vacuum applied to suction cup 532 and suction cup 533 may be removed by pressurizing suction cup 532 and suction cup 533.

This pressurization of these suction cups may provide the force needed to lift suction cup 532 and suction cup 533 off of curved surface 1102. In particular, this force may be provided by, for example, without limitation, cushion of air 1106 under suction cup 532 and cushion of air 1108 under suction cup 533. When suction cup 532 and suction cup 533 are lifted off of curved surface 1102, first frame 514 may be moved along axis 1104 to a desired location.

Further, leg 530 in Figure 9 and leg 531 in Figure 7 may be moved such that suction cup 532 and suction cup 533 may not come in contact with curved surface 1102 while first frame 514 is moved. In some illustrative examples, leg 530 and leg 531 may not need to be moved, because cushion of air 1106 and cushion of air 1108 may provide force sufficient to lift suction cup 532 and suction cup 533, respectively, off of curved surface 1102 as first frame 514 is moved along axis 1104.

With reference now to Figures 12-15, illustrations of a crawler assembly system on a workpiece are depicted in accordance with an advantageous embodiment. In these illustrative examples, crawler assembly system 500 in Figures 12-15 has the configuration presented in Figure 10.

Turning now to Figure 12, crawler assembly system 500 may be placed on workpiece 1200. Suction cups 532, 533, 546, 547,

600, and 548 may be attached to surface 1202 of workpiece 1200. Suction cups 532, 533, 546, 547, 600, and 548 may be attached to surface 1202 using a vacuum provided by vacuum and pressure unit 506.

5 As depicted in this example, electromagnetic unit 504 may attach to magnetic material 1204 positioned under workpiece 1200 to provide additional attachment of crawler assembly system 500 to workpiece 1200 in addition to the attachment provided by suction cups 532, 533, 546, 547, 600, and 548.

10 In this illustrative example, first frame 514 may be in position 1206 on workpiece 1200. First frame 514 may be in position 1206 such that fastener unit 581 may be placed over location 1208 on workpiece 1200. Fastener unit 581 for end effector 508 may be used to perform fastening operations at
15 location 1208 on workpiece 1200.

In **Figure 13**, when fastening operations have been completed, controller 512 may release the attachment of electromagnetic unit 504 from surface 1202 of workpiece 1200. Further, vacuum and pressure unit 506 may apply pressure to
20 suction cup 532 and suction cup 533 to lift suction cup 532 and suction cup 533 off of surface 1202.

Turning now to **Figure 14**, with suction cup 532 and suction cup 533 no longer in contact with surface 1202, first frame 514 may be moved from position 1204 in **Figures 12** and **13**
25 in the direction of arrow 1400 to position 1402. Second frame 516 may not move while first frame 514 is moved.

In **Figure 15**, controller 512 may control electromagnetic unit 504 such that electromagnetic unit 504 attaches to surface 1202. Further, vacuum and pressure unit 506 may apply
30 a vacuum to suction cup 532 and suction cup 533 such that suction cup 532 and suction cup 533 attach to surface 1202. With first frame 514 at position 1402 and suction cup 532 and suction cup 533 attached to surface 1202, fastener system 581

may be used to perform fastening operations at location **1500** on workpiece **1200**.

With reference now to **Figure 16**, an illustration of a crawler assembly system is depicted in accordance with an advantageous embodiment. In this illustrative example, crawler assembly system **1600** may be an example of one implementation of crawler assembly system **402** in **Figure 4** and/or crawler assembly system **308** in **Figure 3**.

As depicted in this example, crawler assembly system **1600** may include frame system **1602**, electromagnetic unit **1604**, vacuum and pressure unit **1606**, end effector **1608**, and sensor system **1610**. Frame system **1602** may comprise first frame **1612**, second frame **1614**, movement system **1616**, first number of legs **1618**, second number of legs **1620**, first number of suction cups **1622**, and second number of suction cups **1624**.

In this illustrative example, first frame **1612** may be positioned within interior **1615** of second frame **1614**. This configuration for crawler assembly system **1600** may be different than the configuration for crawler assembly system **500** in **Figure 5** and in **Figure 9**.

First number of legs **1618** may be associated with first frame **1612** and may include leg **1640** and leg **1641**. Second number of legs **1620** may be associated with second frame **1614** and may include legs **1626**, **1627**, **1628**, **1629**, **1630**, **1631**, **1632**, **1633**, **1634**, **1635**, **1636**, **1637**, **1638**, and **1639**.

First number of suction cups **1622** may include suction cup **1643** attached to leg **1641** and another suction cup (not shown) attached to leg **1640**. Second number of suction cups **1624** may include suction cups **1644**, **1645**, **1646**, **1647**, **1648**, **1649**, **1650**, **1651**, **1652**, **1653**, **1654**, **1655**, **1656**, and **1657** attached to legs **1626**, **1627**, **1628**, **1629**, **1630**, **1631**, **1632**, **1633**, **1634**, **1635**, **1636**, **1637**, **1638**, and **1639**, respectively.

In these illustrative examples, movement system **1616** may be configured to move first frame **1612** relative to second

frame **1614**. Movement system **1616** may be configured to move first frame **1612** and/or second frame **1614** along axis **1617**.

Further, movement system **1616** may be configured to move first number of legs **1618** and/or second number of legs **1620** vertically such that first number of suction cups **1622** and/or second number of suction cups **1624** may all contact the surface of a workpiece (not shown).

Movement system **1616** may include motors **1658, 1659, 1660, 1661, 1662, 1663, 1664, 1665, 1666, 1667, 1668, 1669, 1670, 1671** associated with legs **1626, 1627, 1628, 1629, 1630, 1631, 1632, 1633, 1634, 1635, 1636, 1637, 1638, and 1639**, respectively. Further, movement system **1616** may include motor **1672** associated with leg **1640**, motor **1673** associated with leg **1641**, and/or other suitable motors not shown in this view.

In this illustrative example, motor **1676** and motor **1677** may be associated with first frame **1612**. Motor **1676** may tilt leg **1640** and/or motor **1677** may tilt leg **1641** relative to the surface of the workpiece such that first number of suction cups **1622** may conform to the surface of the workpiece.

Electromagnetic unit **1604** may provide additional attachment for crawler assembly system **1600** to a workpiece. Additionally, end effector **1608** may include fastener system **1678** and drill unit **1680**. Fastener system **1678** and drill unit **1680** may be associated with first frame **1612**. Fastener system **1678** may be used to perform fastening operations on the workpiece. Drill unit **1680** may be used to perform drilling operations on the workpiece.

Sensor system **1610** may be used to identify the location on the workpiece at which to perform operations. Further, sensor system **1610** may be used to position end effector **1608** to perform the operations and/or inspect the operations being performed.

With reference now to **Figure 17**, an illustration of a flowchart of a process for performing operations on a

workpiece is depicted in accordance with an advantageous embodiment. The process illustrated in **Figure 17** may be implemented using crawler assembly system **402** in **Figure 4**.

The process may begin by selecting a location to which to
5 move crawler assembly system **402** (operation **1700**). Crawler assembly system **402** may comprise frame system **408** having first frame **420**, second frame **422**, first number of suction cups **430**, second number of suction cups **432**, and controller **410**. Frame system **408** may be configured to hold end effector **416**. End
10 effector **416** may be configured to perform number of operations **404**.

The process may then move crawler assembly system **402** to the selected location (operation **1702**). Next, the process may perform number of operations **404** at the selected location on
15 workpiece **406** (operation **1704**).

Thereafter, the process may determine whether another location is present for processing (operation **1706**). If another location is present for processing, the process returns to operation **1700**. Otherwise, the process may
20 terminate.

With reference now to **Figure 18**, an illustration of a flowchart of a process for moving a crawler assembly system is depicted in accordance with an advantageous embodiment. The process illustrated in **Figure 18** may be implemented using
25 crawler assembly system **402** in **Figure 4**. This process may be a more-detailed process for operation **1702** in **Figure 17**.

The process may begin by applying pressure **450** to first number of suction cups **430** (operation **1800**). Pressure **450** may provide force **452** that may lift first number of suction cups
30 **430** off of surface **440** of workpiece **406**. In this illustrative example, vacuum **436** may be applied to second number of suction cups **432** such that second number of suction cups **432** may be attached to surface **440** of workpiece **406**.

The process may then disengage electromagnetic unit **412** from workpiece **406** (operation **1802**). Next, the process may move first frame **420** to a selected location (operation **1804**). Second frame **422** may not move when first frame **420** is moved to
5 the selected location.

Thereafter, the process may apply vacuum **436** to first number of suction cups **430** (operation **1806**). Next, the process may engage electromagnetic unit **412** such that electromagnetic unit **412** attaches to workpiece **406** (operation
10 **1808**).

The process may then apply pressure to second number of suction cups **432** to remove vacuum **436** applied to second number of suction cups **432** (operation **1810**). Next, the process may move second frame **422** (operation **1812**). Thereafter, the
15 process may determine whether movement of crawler assembly system **402** to the selected location has been completed (operation **1814**). If movement of crawler assembly system **402** to the selected location has not been completed, the process may return to operation **1800** as described above. Otherwise,
20 the process may terminate.

With reference now to **Figure 19**, an illustration of a flowchart of a process for adjusting the legs of a crawler assembly system is depicted in accordance with an advantageous embodiment. The process illustrated in **Figure 19** may be
25 implemented using crawler assembly system **402** in **Figure 4**.

The process may begin by identifying the contour of surface **440** of workpiece **406** (operation **1900**). For example, without limitation, in operation **1900**, the contour may be identified as curved, jagged, straight, and/or having some
30 other type of contour. Additionally, the contour may be identified as a complex contour in which the contour is curved in at least two directions.

Thereafter, the process may select a number of legs within first number of legs **426** and/or second number of legs

428 (operation **1902**). The process may then adjust the selected number of legs (operation **1904**), with the process terminating thereafter.

In operation **1904**, the selected number of legs may be
5 adjusted by moving at least a portion of the selected number of legs vertically to adjust for the contour of surface **440**. Further, the selected number of legs may be adjusted by tilting at least a portion of the selected number of legs in
10 second number of legs **428** relative to surface **440**. Tilting of this portion of the selected number of legs may allow electromagnetic unit **412** to be tilted such that electromagnetic unit **412** may attach to surface **440**.

The flowcharts and block diagrams in the different depicted embodiments illustrate the architecture,
15 functionality, and operation of some possible implementations of apparatus and methods in different advantageous embodiments. In this regard, each block in the flowcharts or block diagrams may represent a module, segment, function, and/or a portion of an operation or step.

20 In some alternative implementations, the function or functions noted in the block may occur out of the order noted in the figures. For example, in some cases, two blocks shown in succession may be executed substantially concurrently, or the blocks may sometimes be executed in the reverse order,
25 depending upon the functionality involved. Also, other blocks may be added in addition to the illustrated blocks in a flowchart or block diagram.

For example, in some advantageous embodiments, operation **1706** may be performed while operation **1704** is being performed.
30 In other words, the determination as to whether to move crawler assembly system **402** to another location may be made while operation **1704** is being performed. Further, if another location is present for processing, operations **1700** and **1702** may also be performed while operation **1704** is being performed.

Thus, the different advantageous embodiments provide a method and apparatus for performing operations on a workpiece. In one advantageous embodiment, an apparatus may comprise a frame system, a first number of suction cups, a second number
5 of suction cups, and a controller. The frame system may have a first frame and a second frame in which the frame system may be configured to hold an end effector. The end effector may be configured to perform a number of operations. The first number of suction cups may be associated with the first frame
10 in which the first number of suction cups is configured for attachment to a workpiece.

The second number of suction cups may be associated with the second frame in which the second number of suction cups may be configured for attachment to a workpiece. The
15 controller may be configured to control an application of a vacuum and a pressure by the first number of suction cups and the second number of suction cups during movement of the first frame and the second frame relative to each other on the workpiece.

20 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
25 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
30 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.

What is claimed is:

1. An apparatus comprising:

a frame system having a first frame and a second frame in which the frame system is configured to hold an end effector that is configured to perform at least one operation in which the first frame is configured for attachment to a workpiece and in which the second frame is configured for attachment to the workpiece;

a controller configured to control attachment of the first frame and the second frame to the workpiece by applying a vacuum and a pressure during movement of the frame system;

an electromagnetic unit associated with the first frame, the electromagnetic unit configured to attract a magnetic material associated with the workpiece such that the electromagnetic unit engages the workpiece and holds the first frame on the workpiece;

a channel extending through the electromagnetic unit configured to receive the end effector and allow the end effector to reach a surface of the workpiece when the electromagnetic unit engages the workpiece;

a first number of suction cups associated with the first frame in which the first number of suction cups is configured for attachment to the workpiece; and

a second number of suction cups associated with the second frame in which the second number of suction cups is configured for the attachment to the workpiece, wherein the controller is configured to control an application of the vacuum and the pressure by the first number of suction cups and the second number of suction cups during the movement of the frame system, the application of pressure including application of a cushion of air configured to lift the first number of suction cups and the second number of suction cups off the surface of the workpiece so as to enable movement of the first frame and the second frame.

2. The apparatus of claim 1, wherein the first frame and the second frame are configured to move relative to each other on the workpiece.

3. The apparatus of claim 1, wherein the frame system further comprises:

a movement system configured to move the first frame and the second frame relative to each other.

4. The apparatus of claim 1, wherein a number of legs connect the first number of suction cups to the first frame and wherein movement of a first portion of the number of legs in a first direction and movement of a second portion of the number of legs in a second direction, while the vacuum is applied to a first portion of the first number of suction cups connected to the first portion of the number of legs and to a second portion of the first number of suction cups connected to the second portion of the number of legs and the pressure is applied to the second number of suction cups, causes the frame system to turn on the surface of the workpiece.

5. The apparatus of claim 4, further comprising:

a first leg in the first portion of the number of legs, wherein the first leg is configured to rotate about a first axis in the first direction, the first leg associated with a single suction cup; and

a second leg in the second portion of the number of legs, wherein the second leg is configured to rotate about the first axis in the second direction, the second leg associated with a single suction cup, and wherein rotation of the first leg in the first direction and the second leg in the second direction about the first axis causes rotation of the frame system about a second axis that is substantially perpendicular to the surface of the workpiece, and wherein the first leg and the second leg are also configured to move in a substantially normal direction with respect to the surface of the workpiece.

6. The apparatus of any one of claims 1 to 5, wherein the end effector extends to the surface of the workpiece and is configured to perform one of drilling and fastening.

7. The apparatus of any one of claims 1 to 5, wherein the channel is configured to receive an end of the end effector and allow the end of the end effector to reach the surface of the workpiece.

8. The apparatus of any one of claims 1 to 7, further comprising:

a vacuum and pressure unit connected to the first number of suction cups and the second number of suction cups, wherein the vacuum and pressure unit is configured to apply both the vacuum and the pressure to the first number of suction cups and the second number of suction cups.

9. The apparatus of claim 1, wherein the frame system further comprises:

a first number of legs connecting the first number of suction cups to the first frame; and

a second number of legs connecting the second number of suction cups to the second frame.

10. The apparatus of claim 9, wherein a movement system is configured to move the first number of legs and the second number of legs to conform to a surface of the workpiece while the end effector is performing the number of operations on the workpiece.

11. The apparatus of claim 1, wherein the controller is configured to:

apply the vacuum to the first number of suction cups to cause the vacuum to be present in each of the first number of suction cups and the pressure to the second number of suction cups to pressurize each suction cup in the second number of suction cups;

move the second frame relative to the first frame while the vacuum present in the each suction cup in the second number of suction cups holds the first frame to the workpiece;

apply the vacuum to the second number of suction cups to cause the vacuum to be present in each of the second number of suction cups after movement of the second frame;

apply the pressure to the first number of suction cups to pressurize the each suction cup in the first number of suction cups after the vacuum is applied to the second number of suction cups; and

move the first frame relative to the second frame while the vacuum present in the each suction cup in the second number of suction cups holds the second frame to the workpiece.

12. The apparatus of claim 11, wherein the electromagnetic unit holds the first frame on the workpiece during the movement of the second frame.

13. The apparatus of claim 11 or 12, wherein the application of the pressure by the first number of suction cups and the second number of suction cups provides a force to lift.

14. The apparatus of any one of claims 1 to 13, further comprising:

the end effector.

15. The apparatus of claim 14, wherein the end effector comprises at least one of a drill unit, a fastener system, a sealant unit, and a vision system.

16. A crawler assembly system comprising:

an end effector comprising at least one of a drill unit, a fastener system, a sealant unit, and a vision system;

a frame system configured to hold the end effector that is configured to perform a number of operations including at least one of drilling and fastening on a workpiece in which the frame system comprises:

a first frame;

a second frame in which the first frame and the second frame are configured to move relative to each other on the workpiece;

a first number of legs in which a first leg in a first portion of the first number of legs is configured to rotate about a first axis in a first direction, in which a second leg in a second portion of the first number of legs is configured to rotate about the first axis in a second direction, and in which rotation of the first leg in the first direction and the second leg in the second direction about the first axis causes rotation of the frame system about a second axis that is substantially perpendicular to a surface of the workpiece;

a second number of legs; and

a movement system configured to move the first frame and the second frame relative to the each other and to move the first number of legs and the second number of legs to conform to the surface of the workpiece while the end effector is performing the number of operations on the workpiece;

a first number of suction cups connected to the first frame by the first number of legs in which the first number of suction cups is configured for attachment to the workpiece and in which a first portion of the first number of suction cups is connected to the first portion of the first number of legs and a second portion of the first number of suction cups is connected to the second portion of the first number of legs;

a second number of suction cups connected to the second frame by the second number of legs in which the second number of suction cups is configured for the attachment to the workpiece;

a controller configured to control an application of a vacuum and a pressure by the first number of suction cups and the second number of suction cups during movement of the frame system in which movement of the first portion of the first number of legs in the first direction and movement of the second portion of the first number of legs in the second direction, while the vacuum is applied to the first portion of the first number of suction cups and to a second portion of the second

number of suction cups and the pressure is applied to the second number of suction cups, causes the frame system to turn on the surface of the workpiece, the application of pressure including application of a cushion of air configured to lift the first number of suction cups and the second number of suction cups off the surface of the workpiece so as to enable movement of the first frame and the second frame;

an electromagnetic unit associated with the first frame in which the electromagnetic unit is configured to attract a magnetic material associated with the workpiece such that the electromagnetic unit holds the first frame on the workpiece and in which a channel extends through the electromagnetic unit and is configured to receive an end of the end effector and allow the end of the end effector to reach the surface of the workpiece, the electromagnet configured to stabilize the end effector when the electromagnet is engaged with the workpiece;

a vacuum and pressure unit connected to the first number of suction cups and the second number of suction cups in which the vacuum and pressure unit is configured to apply at least one of the vacuum and the pressure to the first number of suction cups and the second number of suction cups; and

a sensor system in communication with the controller, the sensor system configured to determine a location of the crawler assembly where the end effector performs the at least one operation.

17. The crawler assembly system of claim 16, wherein the controller is configured to:

apply the vacuum to the first number of suction cups and the pressure to the second number of suction cups;

move the second frame relative to the first frame while the second number of suction cups holds the first frame to the workpiece;

apply the vacuum to the second number of suction cups after movement of the second frame;

apply the pressure to the first number of suction cups after the vacuum is applied to the second number of suction cups; and

move the first frame relative to the second frame while the second number of suction cups holds the second frame to the workpiece.

18. A crawler assembly for performing an operation on a workpiece having a curved surface, the crawler assembly comprising:

- an end effector configured to perform at least one of drilling or fastening;

- a first frame;

- a second frame located inside of the first frame, the end effector attached to the second frame, the first frame is configured for attachment to a workpiece and the second frame configured for attachment to the workpiece;

- a controller configured to control attachment of the first frame and the second frame to the workpiece by applying a vacuum and a pressure during movement of the first frame and the second frame;

- an electromagnetic unit associated with the second frame, the electromagnetic unit configured to attract a magnetic material associated with the workpiece such that the electromagnetic unit engages the workpiece and holds the first frame on the workpiece, a channel extending through the electromagnetic unit configured to receive the end effector and allow the end effector to reach a surface of the workpiece when the electromagnetic unit engages the workpiece;

- a sensor system associated with the controller and configured to determine a location of the crawler assembly where the end effector performs the at least one operation and to inspect the location;

- a first number of suction cups associated with the first frame in which the first number of suction cups is configured for attachment to the workpiece; and

a second number of suction cups associated with the second frame in which the second number of suction cups is configured for the attachment to the workpiece, wherein the controller is configured to control an application of the vacuum and the pressure by the first number of suction cups and the second number of suction cups during the movement of the frame system, the application of pressure including application of a cushion of air configured to lift the first number of suction cups and the second number of suction cups off the surface of the workpiece so as to enable movement of the first frame and the second frame.

19. A method for performing operations on a workpiece, the method comprising:

- holding a first frame in a frame system on the workpiece by applying a vacuum to the first frame, wherein the frame system is part of a crawler assembly system, the crawler assembly system comprises an end effector associated with the frame system and configured to perform an operation on the workpiece, the workpiece is a portion of a structure of a vehicle or building, and wherein the workpiece includes magnetic material;

- detaching a second frame in the frame system from the workpiece by applying a pressure to the second frame;

- moving the second frame to a location on the workpiece;

- attaching the second frame to the workpiece by applying the vacuum to the second frame;

- attracting the magnetic material of the workpiece with an electromagnetic unit associated with the first frame to aid in the attaching of the first frame to the workpiece, wherein a channel extending through the electromagnetic unit receives the end effector and allows the end effector to reach a surface of the workpiece when the electromagnetic unit attracts the magnetic material of the workpiece; and

- performing the operation on the workpiece.

20. The method of claim 19, wherein the crawler system further comprises:

a first number of suction cups associated with the first frame in which the first number of suction cups is configured for attachment to the workpiece;

a second number of suction cups associated with the second frame in which the second number of suction cups is configured for the attachment to the workpiece; and

a controller configured to control an application of the vacuum and the pressure by the first number of suction cups and the second number of suction cups during movement of the frame system.

21. The method of claim 20, wherein a number of legs connect the first number of suction cups to the first frame and the method further comprises:

applying the vacuum to a first portion of the first number of suction cups connected to a first portion of the number of legs and to a second portion of the first number of suction cups connected to a second portion of the number of legs;

applying the pressure to the second number of suction cups; and

moving the first portion of the number of legs in a first direction and the second portion of the number of legs in a second direction such that the frame system turns on the surface of the workpiece.

22. The method of claim 21, wherein the step of moving the first portion of the number of legs in the first direction and the second portion of the number of legs in the second direction such that the frame system turns on the surface of the workpiece comprises:

rotating a first leg in the first portion of the number of legs in the first direction about a first axis; and

rotating a second leg in the second portion of the number of legs in the second direction about the first axis, wherein rotation of the first leg and the second leg about the first

axis causes rotation of the frame system about a second axis that is substantially perpendicular to the surface of the workpiece.

23. The method of claim 20, wherein the step of holding the first frame in the frame system on the workpiece by applying the vacuum to the first frame comprises applying the vacuum to the first number of suction cups to hold the first frame in the frame system on the workpiece,

wherein the step of detaching the second frame in the frame system from the workpiece by applying the pressure to the second frame comprises applying the pressure to the second number of suction cups to detach the second frame in the frame system from the workpiece,

wherein the step of attaching the second frame to the workpiece by applying the vacuum to the second frame comprises applying the vacuum to the second number of suction cups after movement of the second frame to attach the second frame to the workpiece, and

wherein the method further comprises:

applying the pressure to the first number of suction cups after the vacuum is applied to the second number of suction cups; and

moving the first frame relative to the second frame while the second number of suction cups holds the second frame on the workpiece.

24. The method of any one of claims 19 to 23, wherein the location is a first location and the method further comprises:

moving the crawler assembly system towards a second location while the end effector performs a number of operations on the workpiece.

25. The method of claim 20, further comprising:

applying both the vacuum and the pressure to the first number of suction cups and the second number of suction cups

through a vacuum and pressure unit connected to the first number of suction cups and the second number of suction cups.

26. The method of claim 20, wherein applying the pressure by the first number of suction cups and the second number of suction cups provides a force to lift.

27. The method of any one of claims 19 to 26, further comprising:

moving the first frame and the second frame relative to each other with a movement system.

28. The method of any one of claims 19 to 27, wherein the end effector comprises at least one of a drill unit, a fastener system, a sealant unit and a vision system.

29. The method of any one of claims 19 to 23, further comprising determining, with a sensor system in communication with a controller, a location of the crawler assembly where the end effector performs at least one operation in a number of operations on the workpiece.

30. The method of any one of claims 19 to 29, wherein the workpiece is a surface of a fuselage of the vehicle.

31. The method of claim 30, wherein the vehicle is one of an aircraft, an automobile, a truck, a spacecraft, a missile, a ship and a submarine.

32. The method of claim 30, wherein the vehicle is one of an aircraft, a spacecraft and a missile.

33. A method for performing operations on a workpiece, the method comprising:

moving a crawler assembly system from a first location on the workpiece to a second location on the workpiece,

wherein the workpiece is a portion of a structure of a vehicle or building, the workpiece includes magnetic material, wherein the crawler assembly system comprises:

a frame system having a first frame and a second frame in which the frame system is configured to hold an end effector that is configured to perform a number of operations;

a first number of suction cups associated with the first frame by a number of legs in which the first number of suction cups is configured for attachment to the workpiece;

a second number of suction cups associated with the second frame in which the second number of suction cups is configured for attachment to the workpiece; and

a controller configured to control an application of a vacuum and a pressure by the first number of suction cups and the second number of suction cups during movement of the frame system, and

wherein the step of moving the crawler assembly system from the first location on the workpiece to the second location on the workpiece comprises:

applying the vacuum to the first number of suction cups and the pressure to the second number of suction cups;

moving the second frame relative to the first frame while the first number of suction cups holds the first frame to the workpiece;

applying the vacuum to the second number of suction cups after movement of the second frame;

applying the pressure to the first number of suction cups after the vacuum is applied to the second number of suction cups;

moving the first frame relative to the second frame while the second number of suction cups holds the second frame to the workpiece;

repeating the steps of applying the vacuum to the first number of suction cups and the pressure to the second number of suction cups;

moving the second frame relative to the first frame while the first number of suction cups holds the first frame to the workpiece;

applying the vacuum to the second number of suction cups after the movement of the second frame;

applying the pressure to the first number of suction cups after the vacuum is applied to the second number of suction cups; and

moving the first frame relative to the second frame while the second number of suction cups holds the second frame to the workpiece until the second location on the workpiece is reached;

applying the vacuum to a first portion of the first number of suction cups connected to a first portion of the number of legs and to a second portion of the first number of suction cups connected to a second portion of the number of legs;

applying the pressure to the second number of suction cups;

rotating a first leg in the first portion of the number of legs in a first direction around a first axis;

rotating a second leg in the second portion of the number of legs in a second direction about the first axis in which rotation of the first leg and the second leg causes rotation of the frame system about a second axis that is substantially perpendicular to a surface of the workpiece;

attracting the magnetic material of the workpiece with an electromagnetic unit associated with the first frame to aid in the attaching of the first frame to the workpiece, wherein a channel extending through the electromagnetic unit receives the end effector and allows the end effector to reach the surface of the workpiece when the electromagnetic unit attracts the magnetic material of the workpiece; and

performing the number of operations at the second location on the workpiece.

34. The method of claim 33, further comprising determining, with a sensor system in communication with the controller, a

location of the crawler assembly where the end effector performs at least one operation in the number of operations on the workpiece.

35. An apparatus comprising:

- a frame system for holding an end effector that is configured to perform a number of operations, the frame system having a first frame and a second frame;

- a first number of suction cups for attachment to a workpiece, associated with the first frame;

- a second number of suction cups for attachment to the workpiece, associated with the second frame; and

- a controller configured to control attachment of the first frame and the second frame to the workpiece by applying a vacuum and a pressure during movement of the frame system, wherein the controller is configured to control an application of the vacuum and the pressure by the first number of suction cups and the second number of suction cups during the movement of the frame system, and wherein the application of the pressure comprises providing a cushion of air to lift a respective suction cup off of the workpiece.

36. The apparatus of claim 35, wherein the first frame and the second frame are configured to move relative to each other on the workpiece.

37. The apparatus of claim 35 or 36, further comprising:

- an electromagnetic unit associated with the first frame, wherein the electromagnetic unit is configured to attract a magnetic material associated with the workpiece such that the electromagnetic unit holds the first frame on the workpiece.

38. The apparatus of any one of claims 35 to 37, further comprising:

- a vacuum and pressure unit connected to the first number of suction cups and the second number of suction cups, wherein the vacuum and pressure unit is configured to apply at least one

of the vacuum and the pressure to the first number of suction cups and the second number of suction cups.

39. The apparatus of any one of claims 35 to 38, wherein the frame system further comprises:

a movement system configured to move the first frame and the second frame relative to each other.

40. The apparatus of any one of claims 35 to 39, wherein the frame system further comprises:

a first number of legs connecting the first number of suction cups to the first frame; and

a second number of legs connecting the second number of suction cups to the second frame.

41. The apparatus of any one of claims 35 to 40, wherein the controller is configured to:

apply the vacuum to the first number of suction cups to cause the vacuum to be present in each of the first number of suction cups and the pressure to the second number of suction cups to pressurize each suction cup in the second number of suction cups;

move the second frame relative to the first frame while the vacuum present in the each suction cup in the second number of suction cups holds the first frame to the workpiece;

apply the vacuum to the second number of suction cups to cause the vacuum to be present in each of the second number of suction cups after movement of the second frame;

apply the pressure to the first number of suction cups to pressurize the each suction cup in the first number of suction cups after the vacuum is applied to the second number of suction cups; and

move the first frame relative to the second frame while the vacuum present in the each suction cup in the second number of suction cups holds the second frame to the workpiece.

42. The apparatus of any one of claims 35 to 41, further comprising:

an end effector.

43. A method for performing operations on a workpiece, the method comprising:

holding a first frame in a frame system on the workpiece by applying a vacuum to the first frame;

detaching a second frame in the frame system from the workpiece by applying a pressure to the second frame, wherein applying the pressure comprises providing a cushion of air to lift the second frame off of the workpiece;

moving the second frame to a location on the workpiece;

attaching the second frame to the workpiece by applying the vacuum to the second frame; and

performing an operation on the workpiece.

44. The method of claim 43, wherein the frame system is part of a crawler assembly system, and wherein the crawler assembly system comprises:

an end effector associated with the frame system and configured to perform the operation;

a first number of suction cups associated with the first frame in which the first number of suction cups are configured for attachment to the workpiece;

a second number of suction cups associated with the second frame in which the second number of suction cups are configured for the attachment to the workpiece; and

a controller configured to control an application of the vacuum and the pressure by the first number of suction cups and the second number of suction cups during movement of the frame system.

45. The method of claim 44, wherein a number of legs connect the first number of suction cups to the first frame, and wherein the method further comprises:

applying the vacuum to a first portion of the first number of suction cups connected to a first portion of the number of legs and to a second portion of the first number of suction cups connected to a second portion of the number of legs;

applying the pressure to the second number of suction cups; and

moving the first portion of the number of legs in a first direction and the second portion of the number of legs in a second direction such that the frame system turns on a surface of the workpiece.

46. The method of claim 45, wherein the step of moving the first portion of the number of legs in the first direction and the second portion of the number of legs in the second direction such that the frame system turns on the surface of the workpiece comprises:

rotating a first leg in the first portion of the number of legs in the first direction about a first axis; and

rotating a second leg in the second portion of the number of legs in the second direction about the first axis, and

wherein rotation of the first leg and the second leg about the first axis causes rotation of the frame system about a second axis that is substantially perpendicular to the surface of the workpiece.

47. The method of claim 44, wherein the step of holding the first frame in the frame system on the workpiece by applying the vacuum to the first frame comprises applying the vacuum to the first number of suction cups to hold the first frame in the frame system on the workpiece,

wherein the step of detaching the second frame in the frame system from the workpiece by applying the pressure to the second frame comprises applying the pressure to the second number of suction cups to detach the second frame in the frame system from the workpiece,

wherein the step of attaching the second frame to the workpiece by applying the vacuum to the second frame comprises

applying the vacuum to the second number of suction cups after movement of the second frame to attach the second frame to the workpiece, and

wherein the method further comprises:

applying the pressure to the first number of suction cups after the vacuum is applied to the second number of suction cups; and

moving the first frame relative to the second frame while the second number of suction cups holds the second frame on the workpiece.

48. The method of any one of claims 44 to 47, wherein the location is a first location, and wherein the method further comprises:

moving the crawler assembly system towards a second location while the end effector performs a number of operations.

1/13

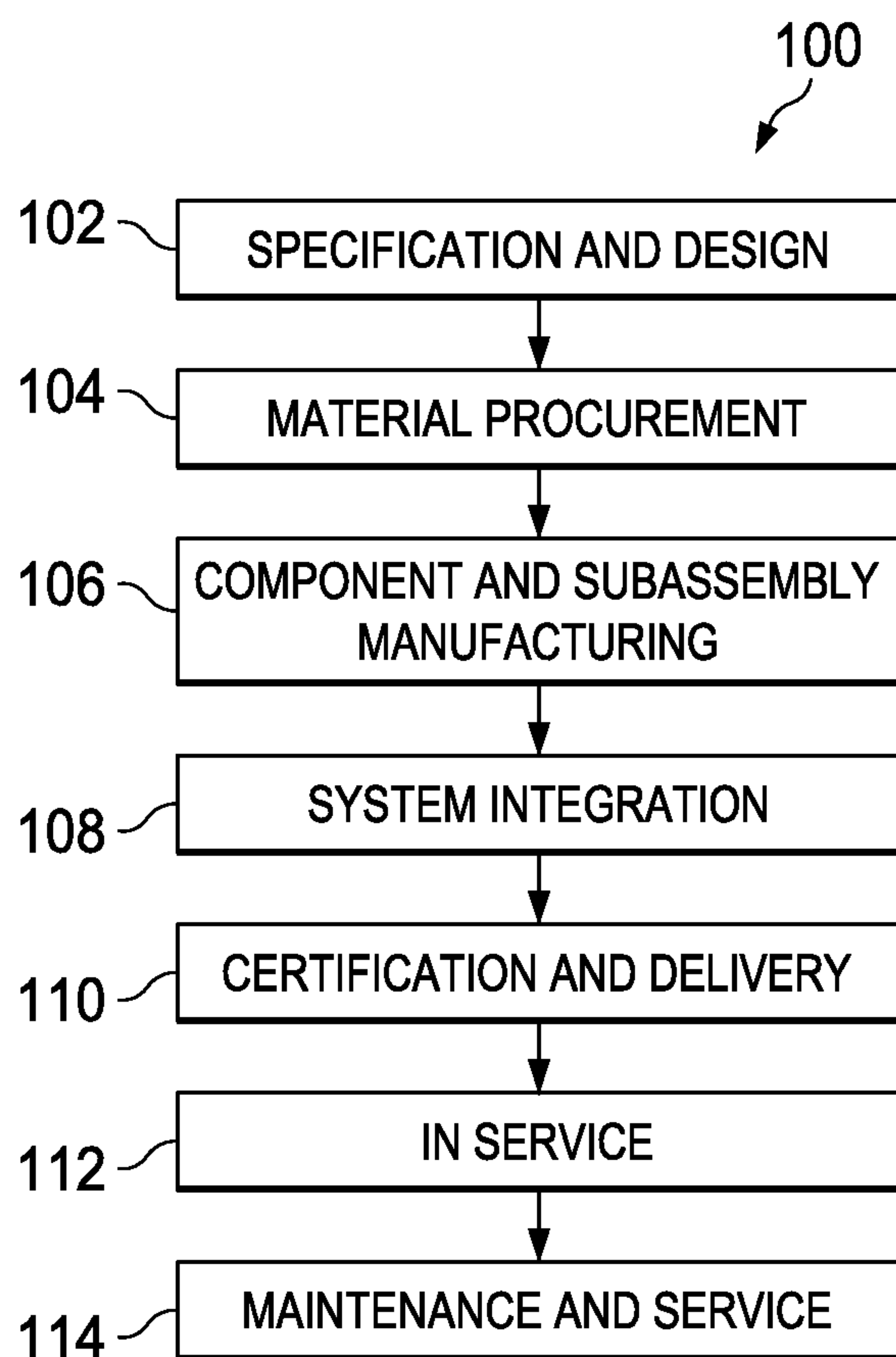


FIG. 1

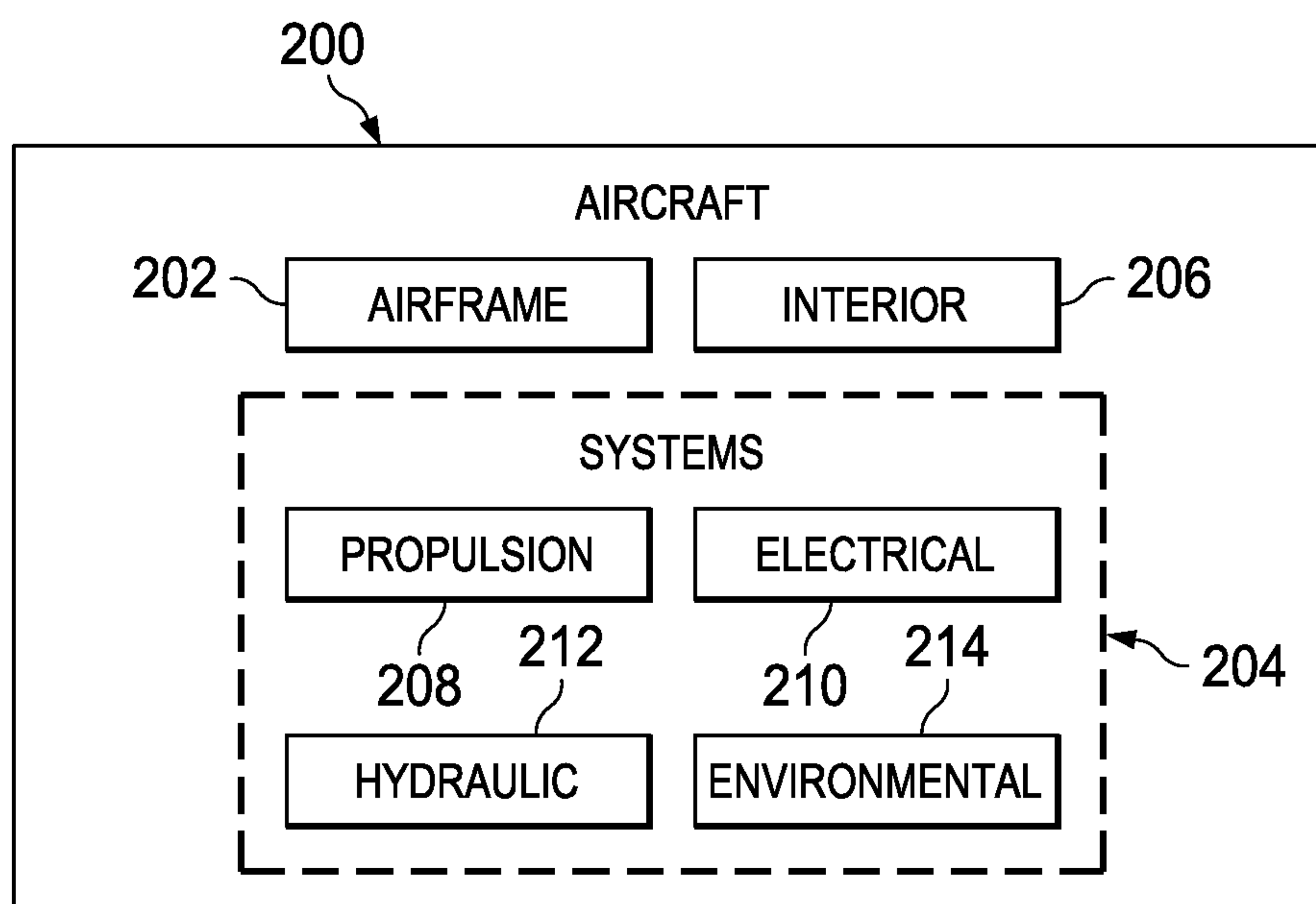


FIG. 2

2/13

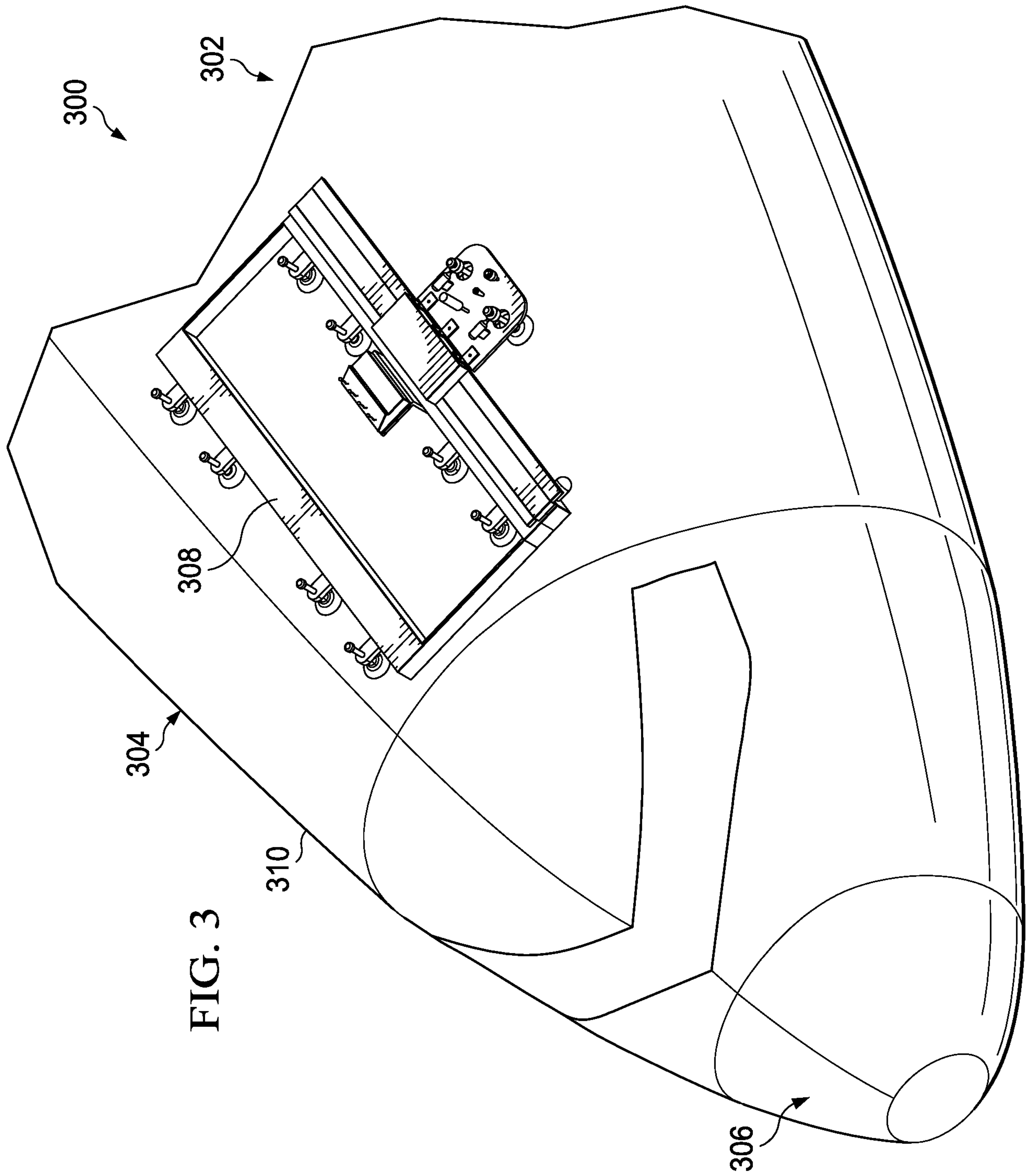
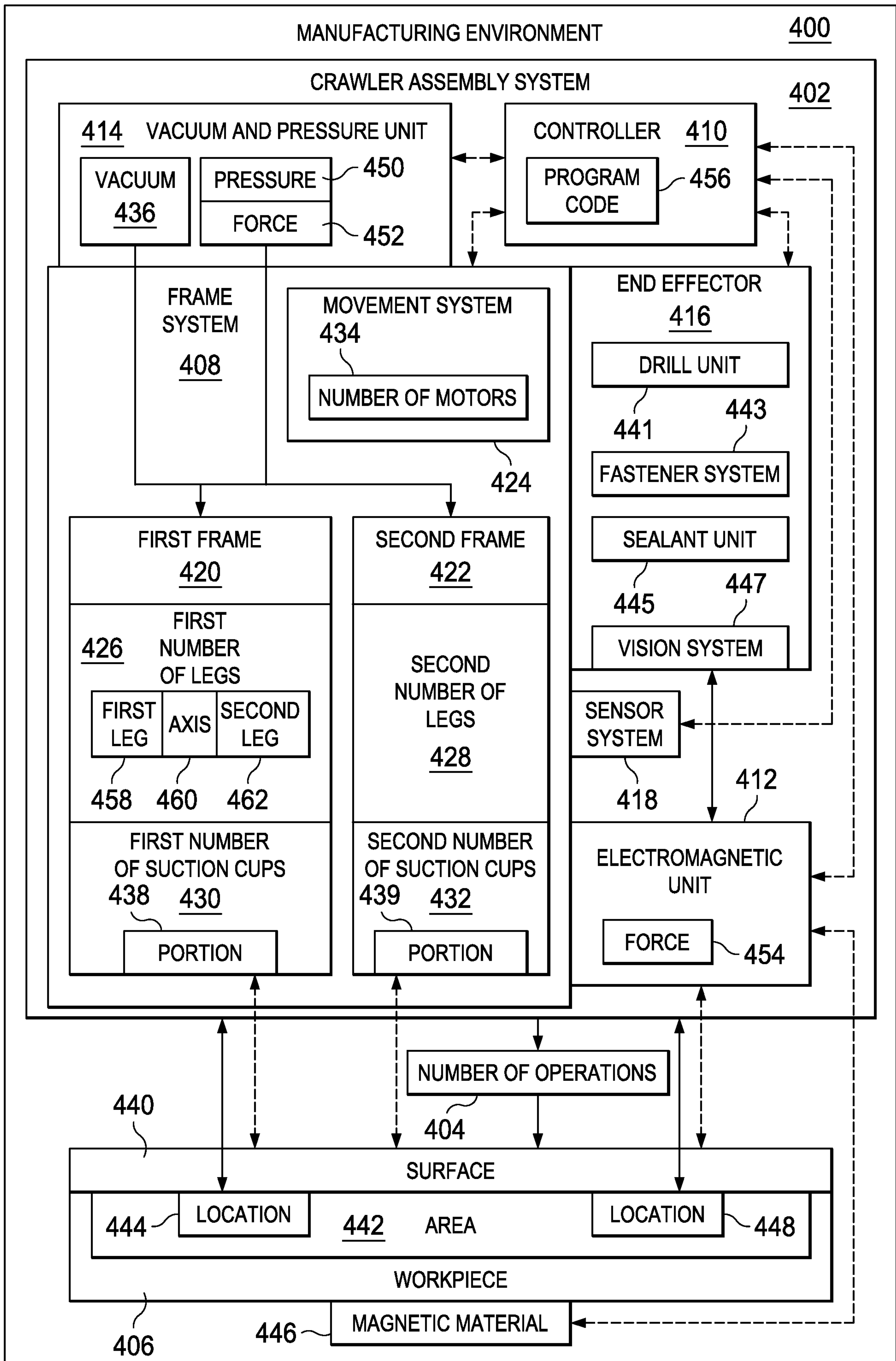
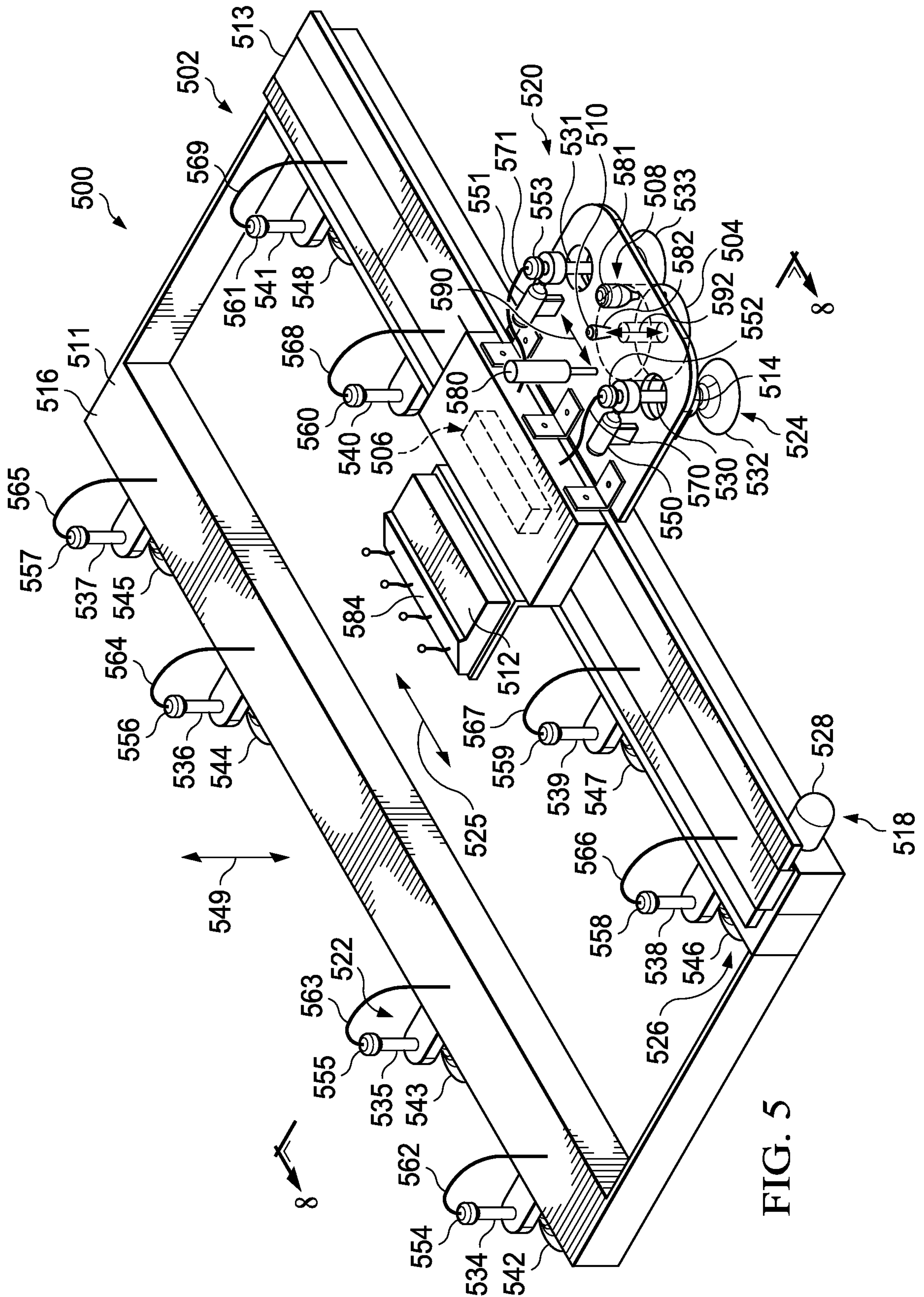


FIG. 4

3/13



4/13



5/13

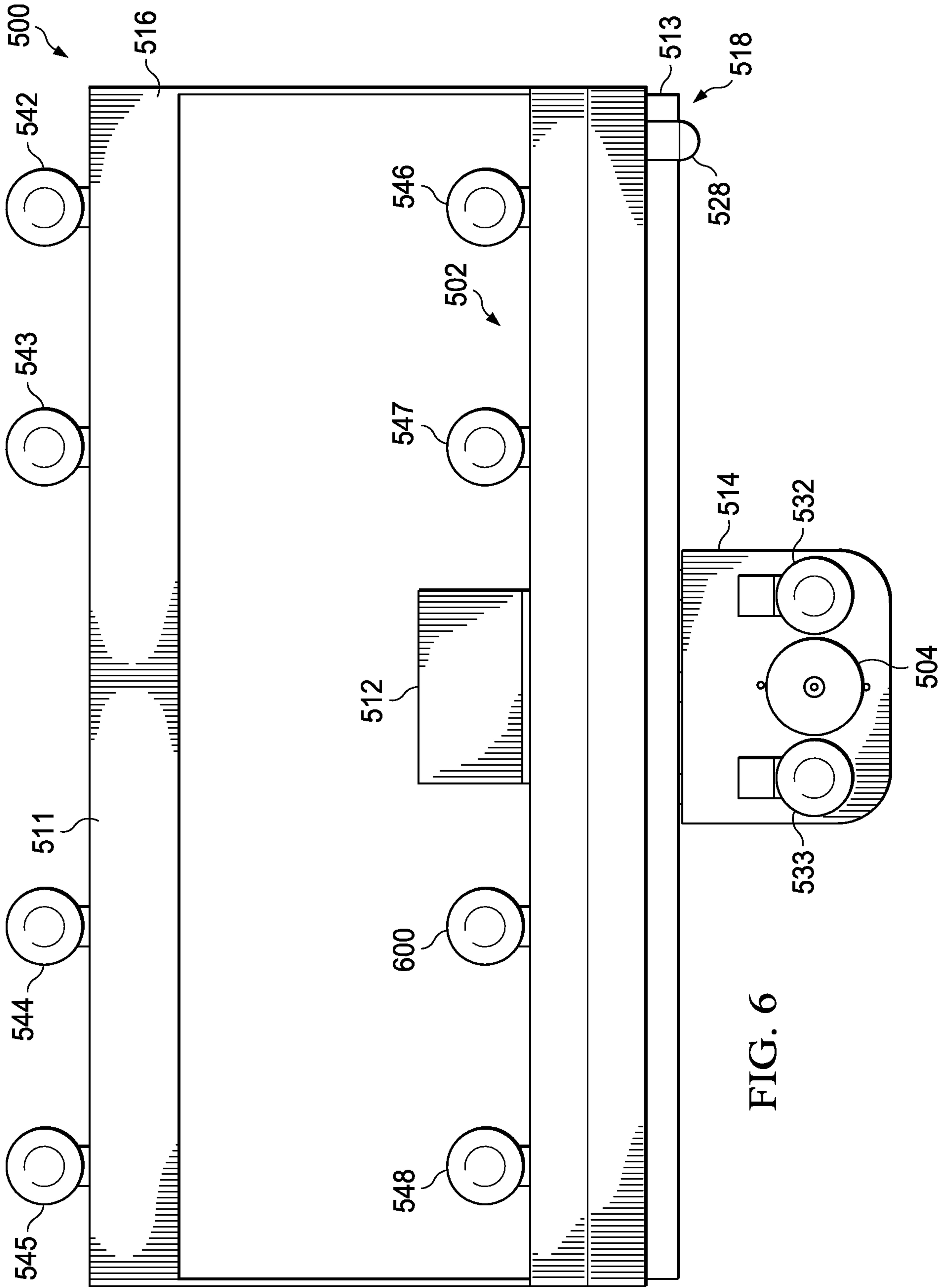


FIG. 6

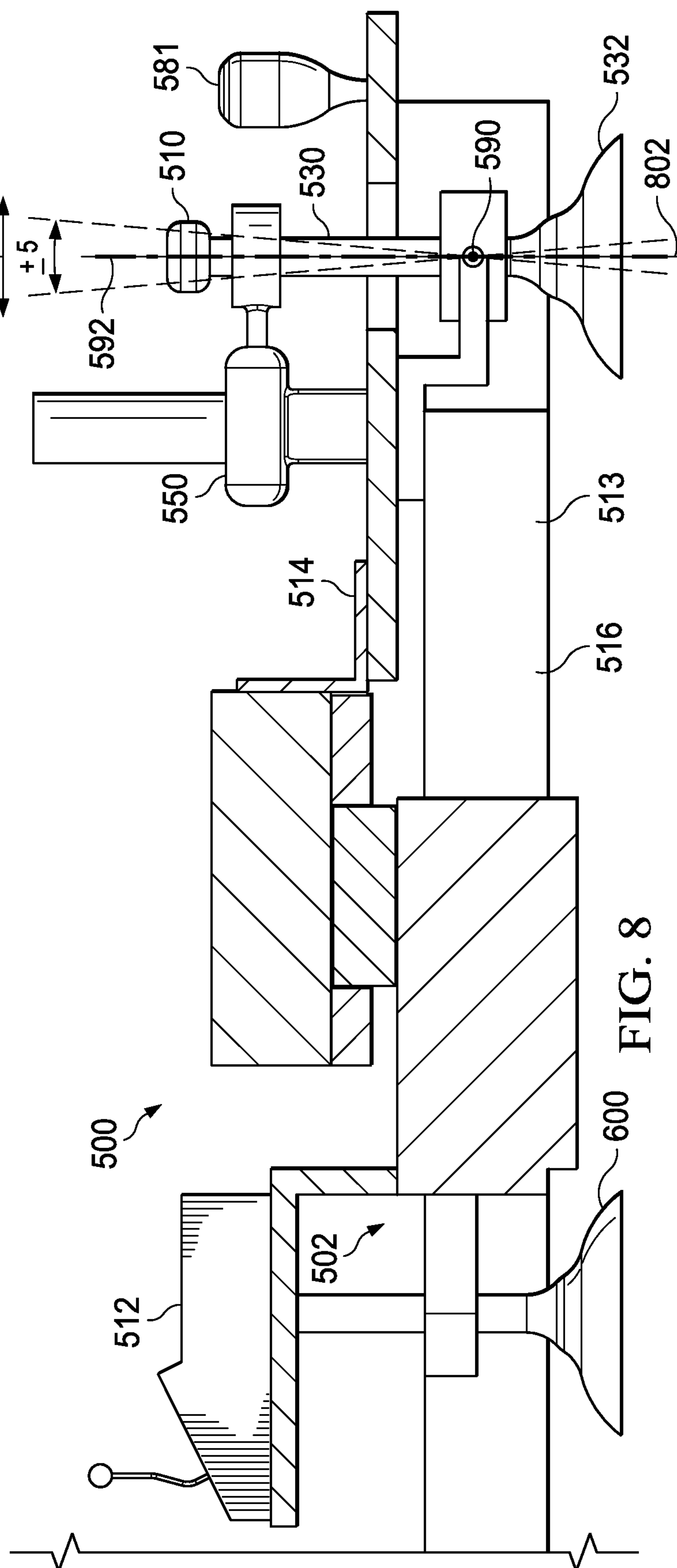
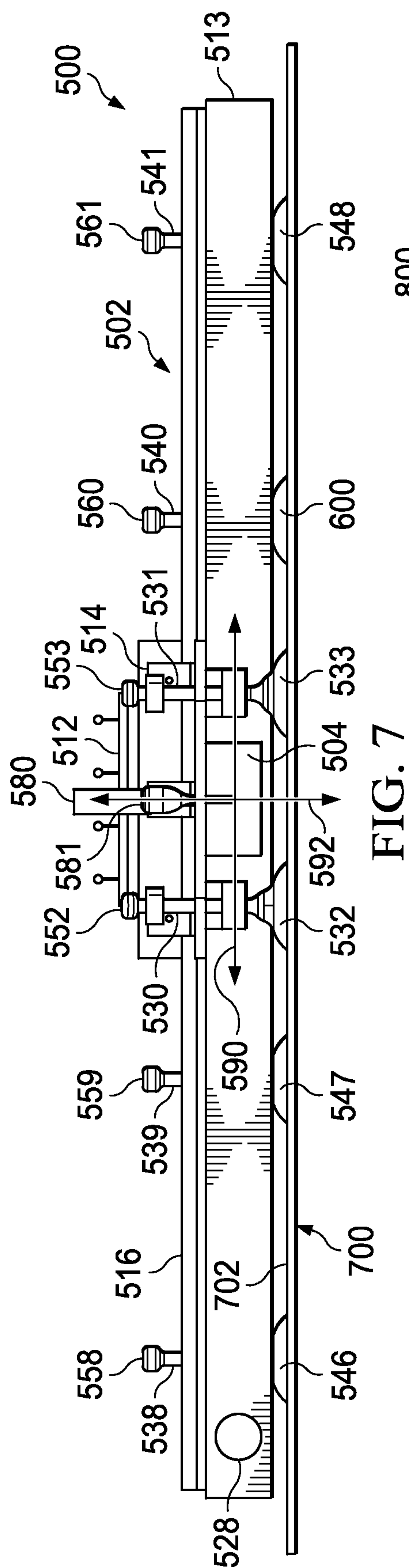
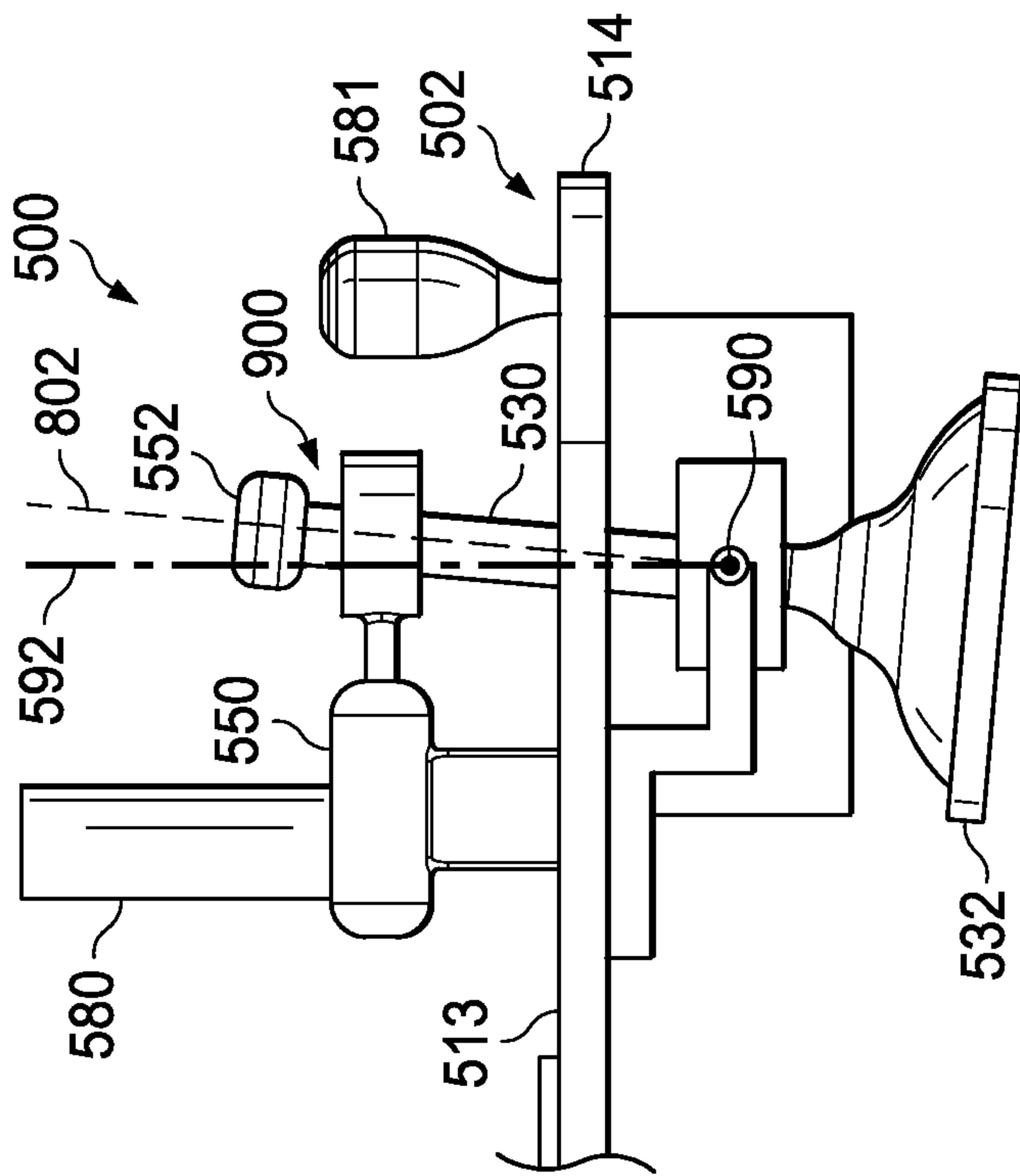
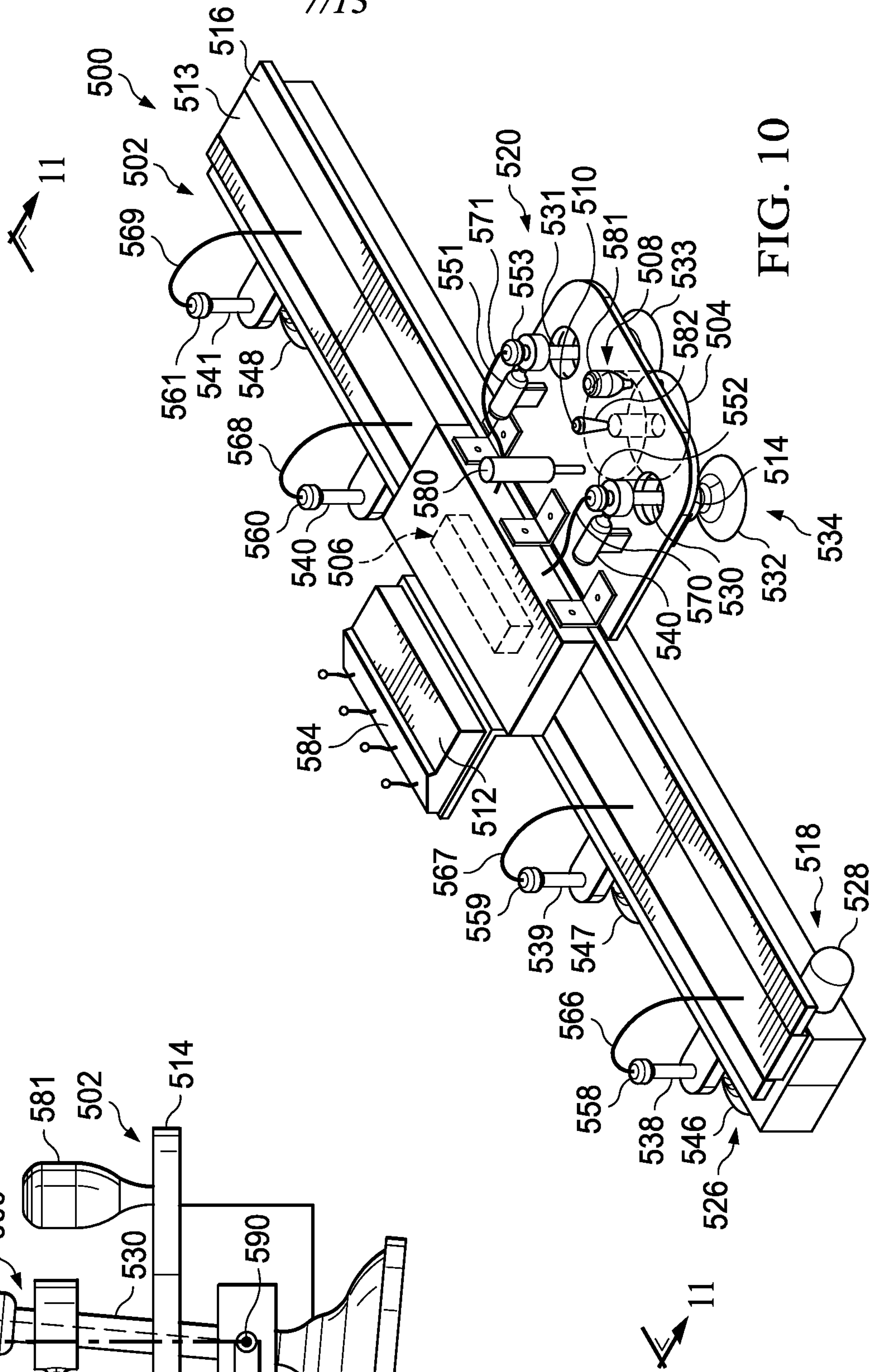


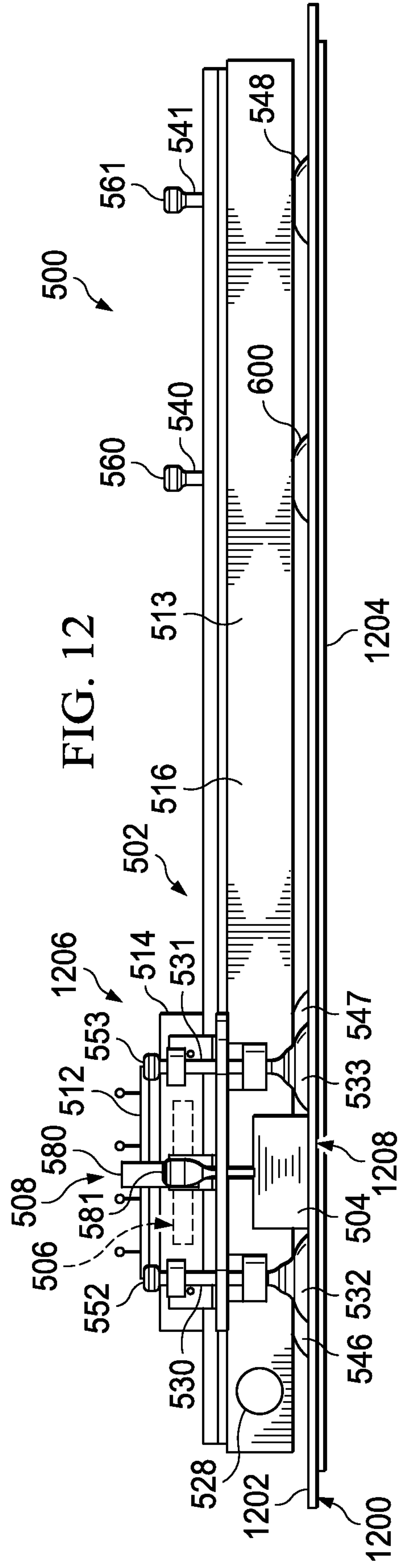
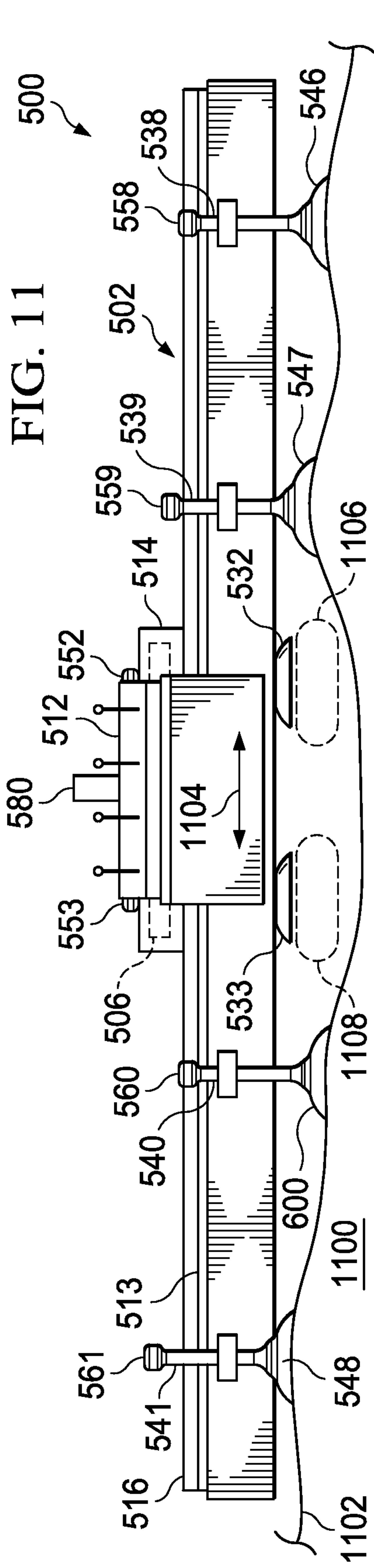
FIG. 9



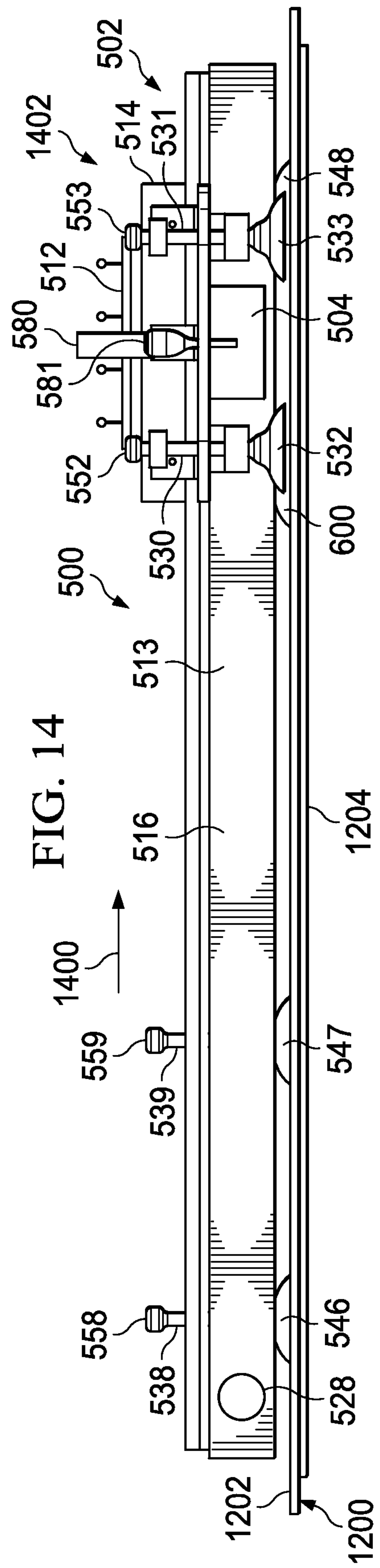
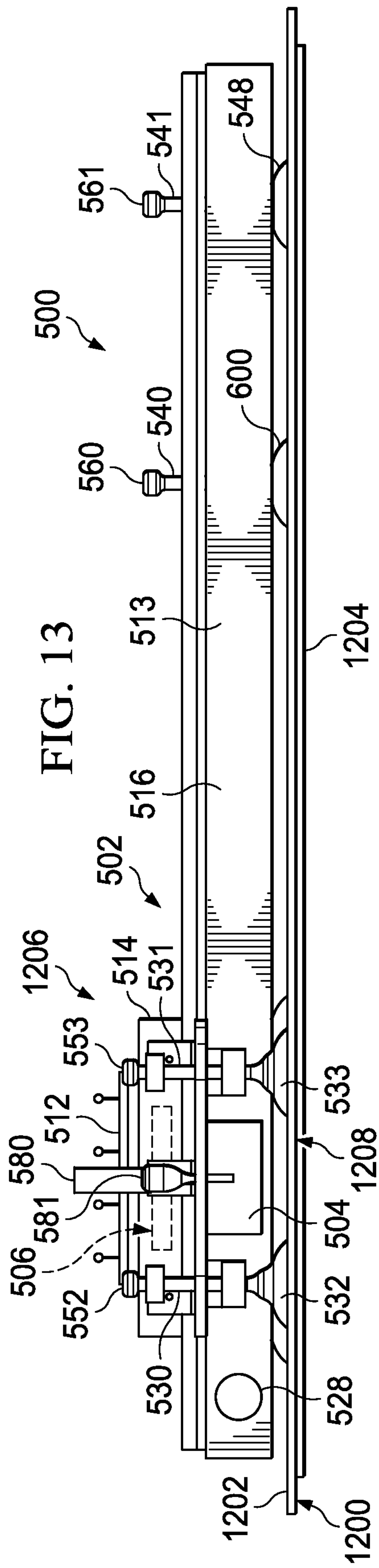
7/13



8/13



9/13



10/13

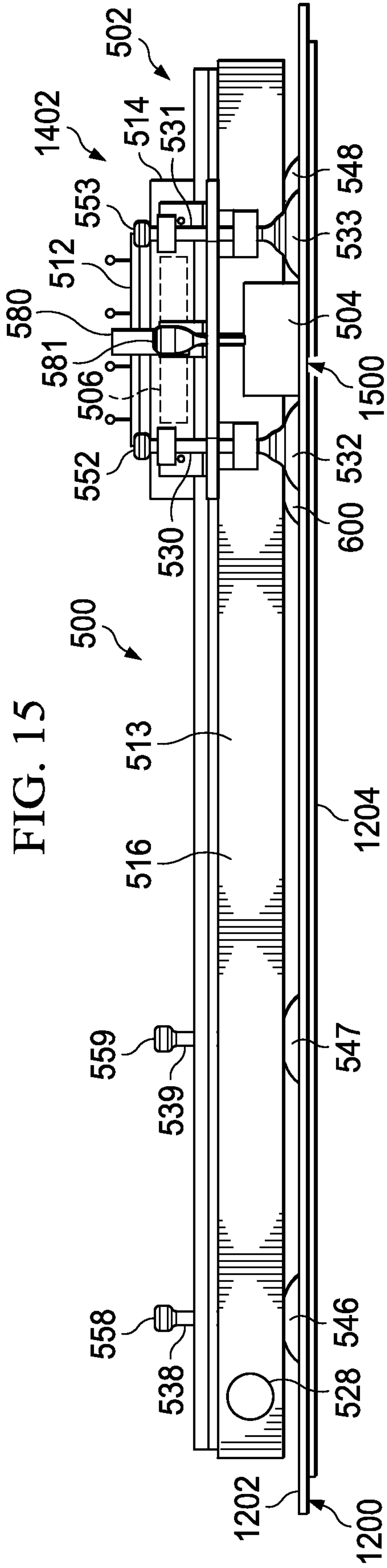
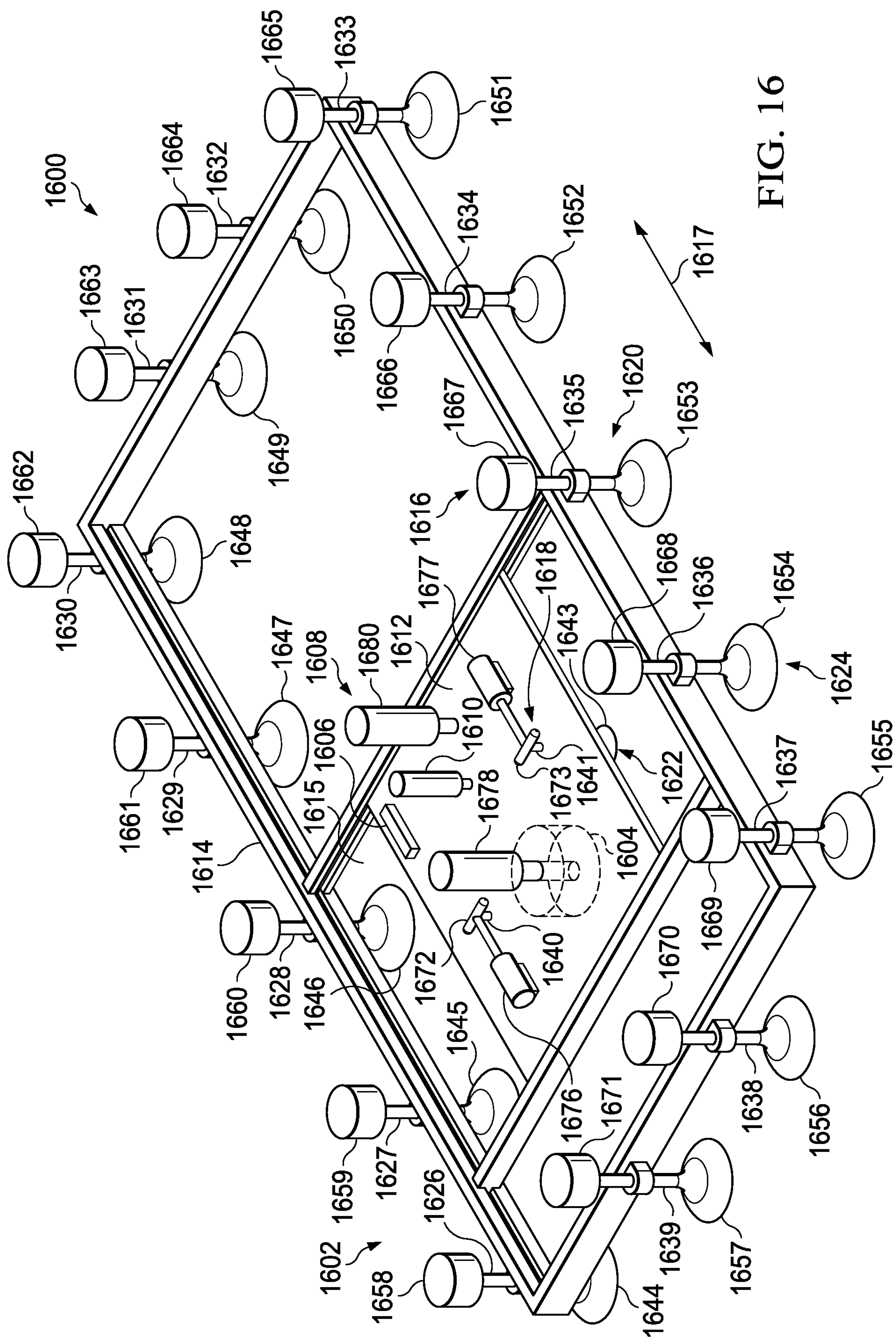


FIG. 15



12/13

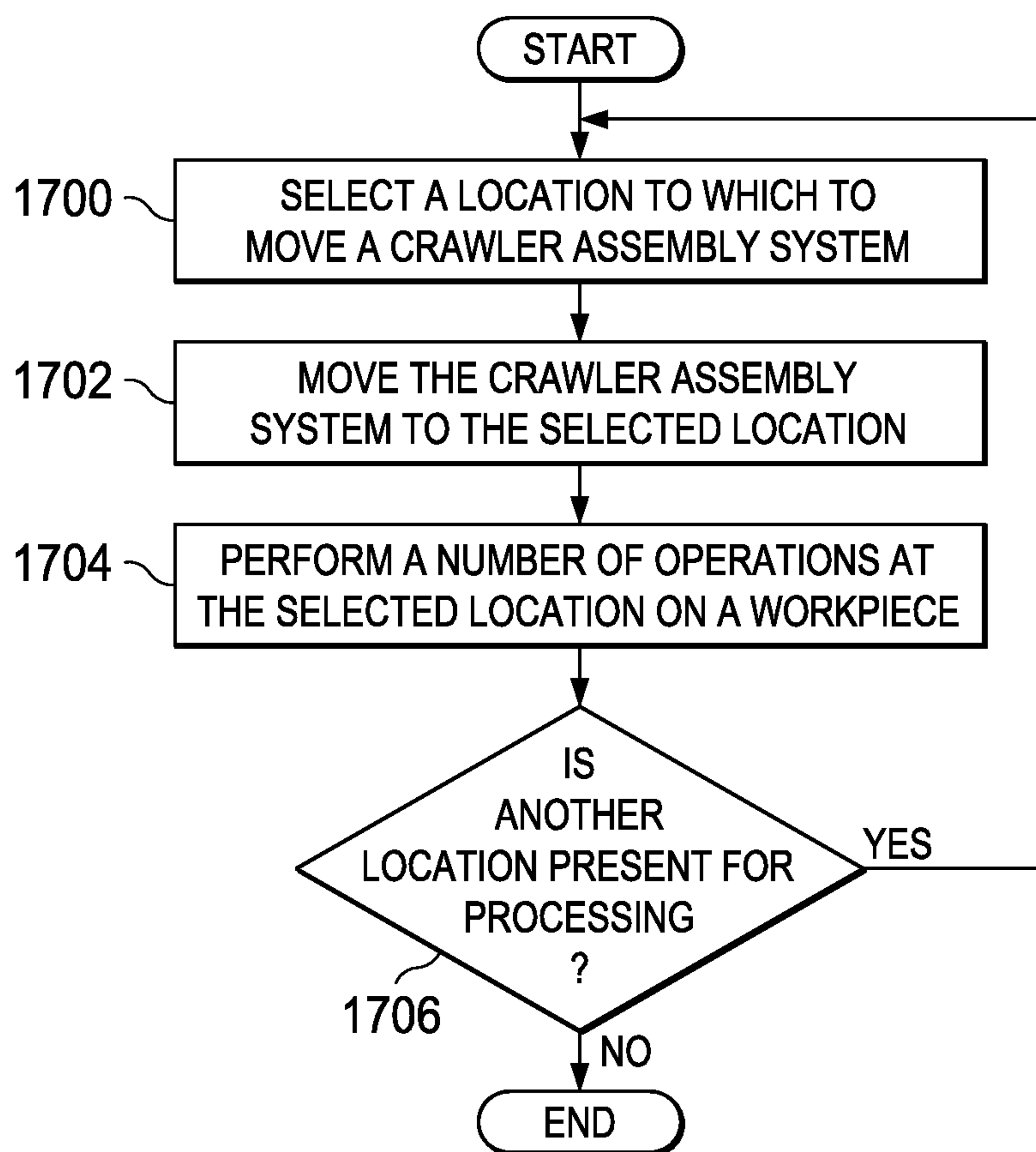


FIG. 17

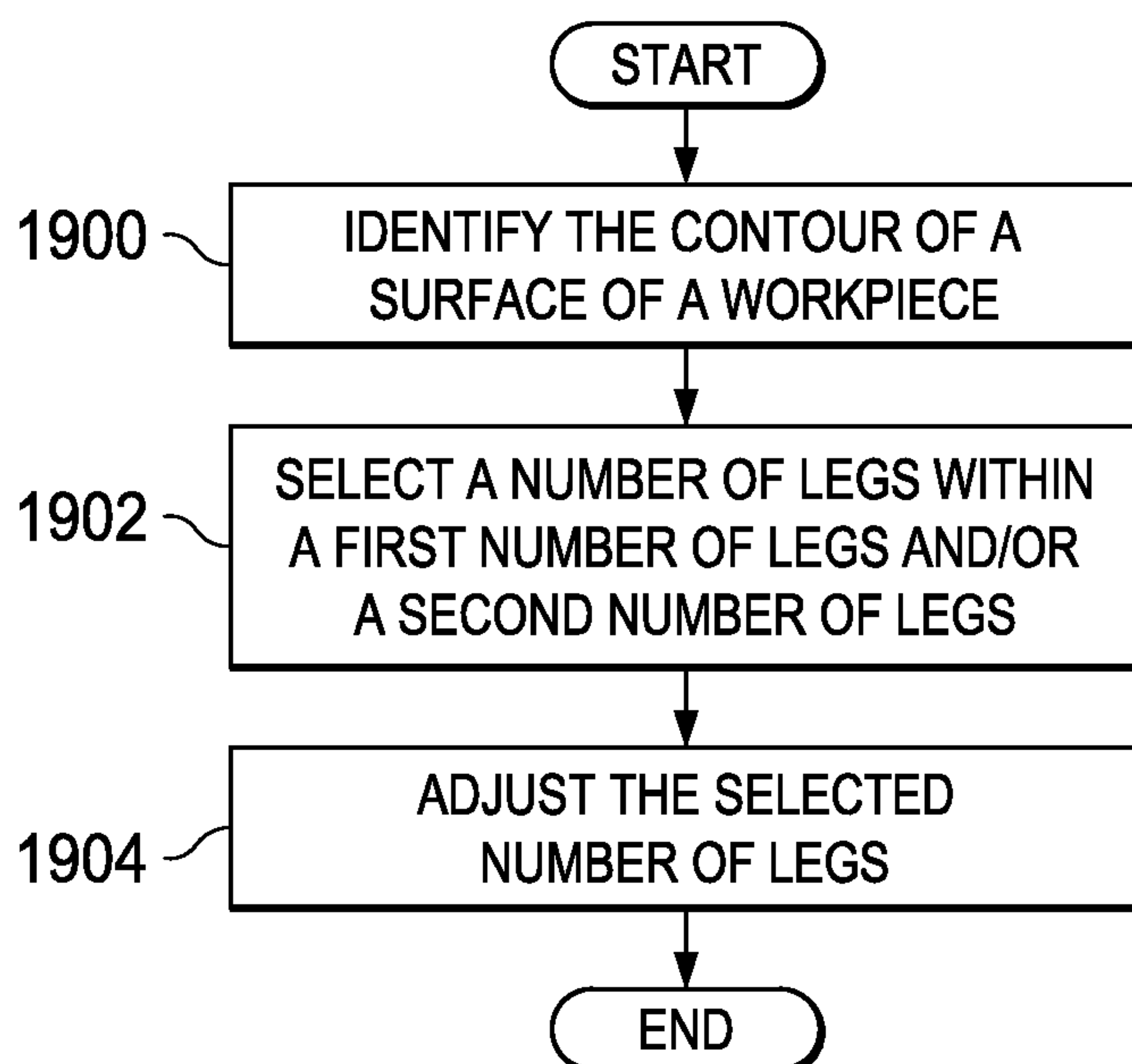


FIG. 19

13/13

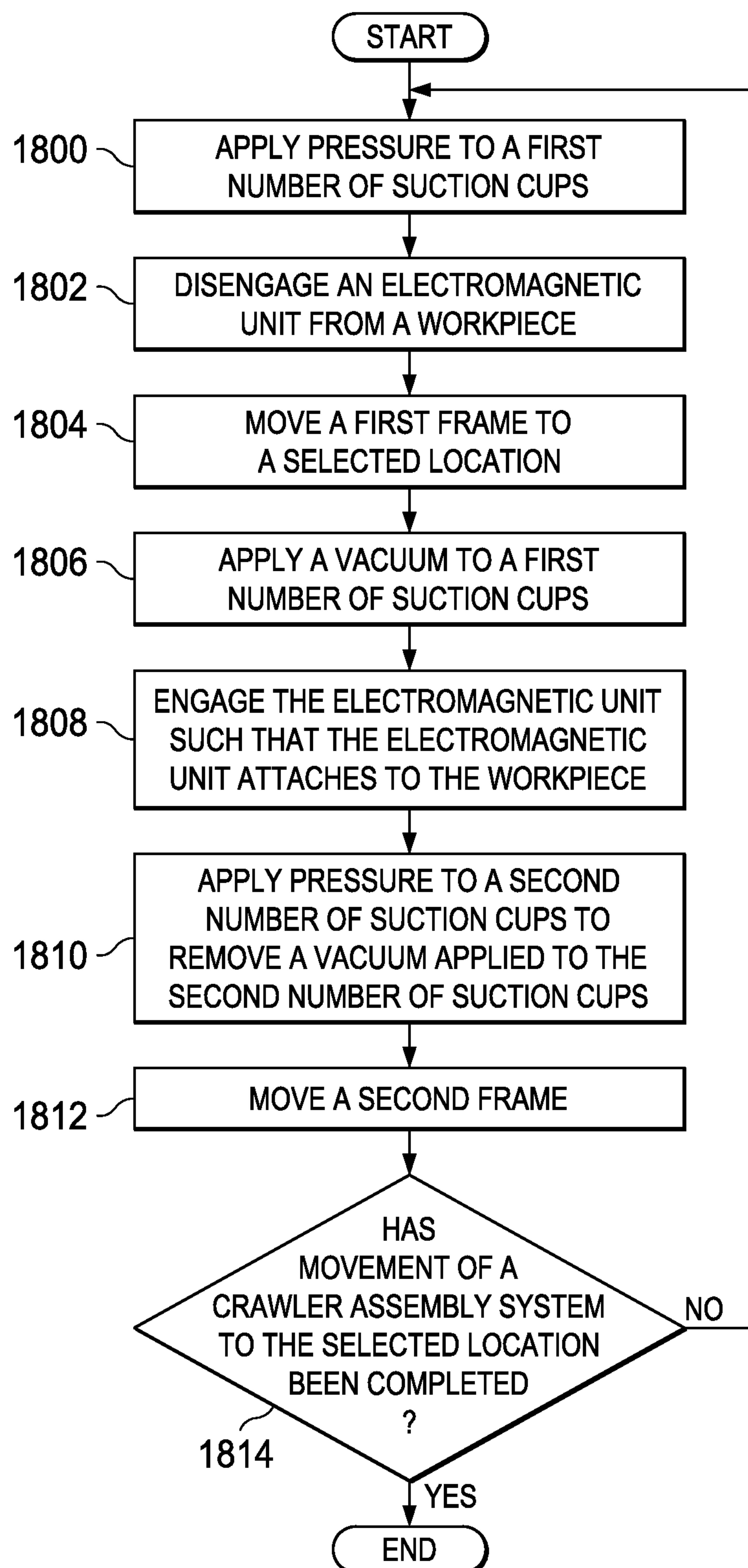


FIG. 18

100

