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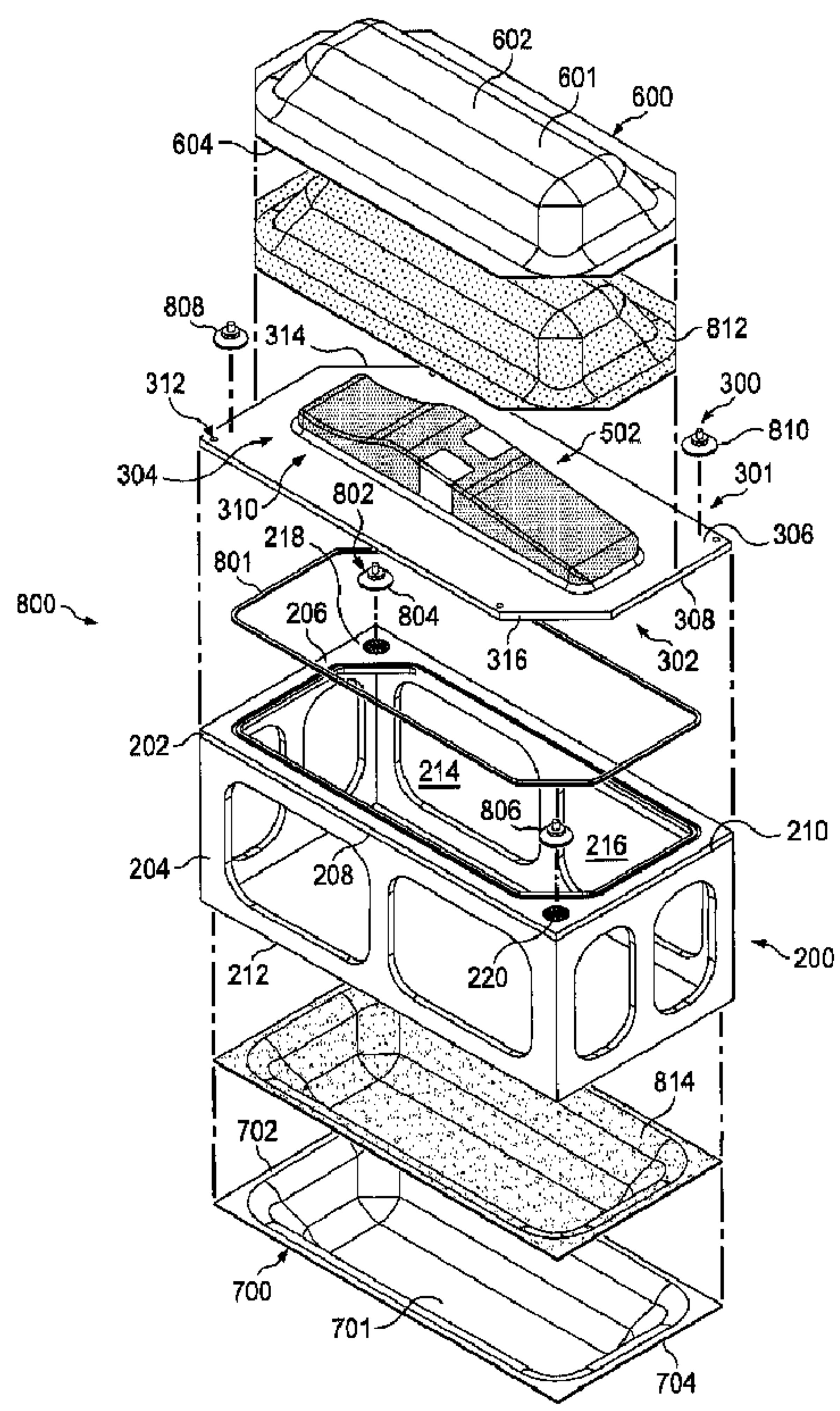
(54) **Titre : SYSTEME DE CUISSON PORTATIF**
(54) **Title: PORTABLE CURING SYSTEM**



(57) **Abrégé/Abstract:**
A method and apparatus for curing a composite workpiece to form a part. In one illustrative embodiment, an apparatus may comprise an object, a portable structure, and a heating system. The object may have a shape selected for a part. The portable

(57) **Abrégé(suite)/Abstract(continued):**

structure may comprise a retaining structure configured to hold the object. The retaining structure may have a first side and a second side. The heating system may be configured to cover the object at the first side of the retaining structure and the second side of the retaining structure. The heating system may be further configured to generate heat for use in curing a workpiece placed over the object to form the part.

ABSTRACT

A method and apparatus for curing a composite workpiece to form a part. In one illustrative embodiment, an apparatus may comprise an object, a portable structure, and a heating system. The object may have a shape selected for a part. The portable structure may comprise a retaining structure configured to hold the object. The retaining structure may have a first side and a second side. The heating system may be configured to cover the object at the first side of the retaining structure and the second side of the retaining structure. The heating system may be further configured to generate heat for use in curing a workpiece placed over the object to form the part.

PORTABLE CURING SYSTEM

BACKGROUND INFORMATION

1. Field:

The present disclosure relates generally to curing and, in particular, to curing composite materials. Still more particularly, the present disclosure relates to a portable curing system for use in curing composite materials.

2. Background:

In some situations, a substance may be hardened or toughened using the process of curing. Typically, the curing process may use heat, pressure, a vacuum, or some combination thereof to cause a chemical reaction in the substance that hardens or toughens the substance. As one illustrative example, heat and/or pressure may be used to cure a composite workpiece to form a composite part. The composite workpiece may comprise any number of composite materials. The composite part may be used in an object such as, for example, without limitation, a vehicle, a piece of equipment, a structural panel, a frame, an aircraft part, an automobile part, a machining tool, a fastener, or some other type of object.

Different types of systems may be used for curing. A curing system may include one or more different types of curing devices. A curing oven and an autoclave may be examples of curing devices that are oftentimes used to cure composite workpieces. A curing oven may generate heat that causes a chemical reaction in a substance placed within the oven once a selected temperature has been reached. An autoclave may use both heat and pressure to cause a chemical reaction in a substance placed within the autoclave.

When manufacturing an object such as, for example, without limitation, an aircraft, different parts for the aircraft may be formed by curing composite workpieces. The manufacturing of these parts may occur in different locations within a manufacturing facility. However, the size and/or weight of some currently available ovens and autoclaves may make moving these devices to the different locations within the manufacturing facility more difficult, time-consuming, and/or expensive than desired. In some cases, moving these devices may be more expensive than purchasing additional devices for use at the different locations.

Additionally, the cost of operating these autoclaves may be greater than desired. For example, without limitation, an autoclave may be used to cure composite workpieces of different sizes. However, the amount of energy needed to reach specified temperatures and specified pressure levels may be greater than desired for smaller composite workpieces. Therefore, it would be desirable to have a method and apparatus that takes into account at least some of the issues discussed above, as well as other possible issues.

SUMMARY

The disclosure describes an apparatus including an object having a shape selected for a part, a portable structure including a retaining structure configured to hold the object, the retaining structure having a first side and a second side. The apparatus further includes a heating system configured to cover the object at the first side of the retaining structure and the second side of the retaining structure. The heating system is configured to generate heat for use in curing a workpiece placed over the object to form the part. The heating system includes a first heating device configured to cover the object at the first side of the retaining structure and a second heating device configured to cover the object at the second side of the retaining structure. At least one of the first heating device and the second heating device is comprised of a deformable material selected such that the at least one of the first heating

device and the second heating device deforms in response to a vacuum to conform to the shape of the object.

The apparatus may further include a number of vacuum ports associated with at least one of the object and the retaining structure and the apparatus also includes a vacuum system connected to the number of vacuum ports and configured to apply a vacuum within a vacuum boundary formed around the object in which the vacuum is used in curing the workpiece placed over the object to form the part.

The vacuum boundary may be formed by at least one of the heating system and a vacuum bag.

The apparatus may include a control system configured to control vacuum pressure generated by the vacuum system to apply the vacuum and an amount of the heat generated by the heating system.

The apparatus may include a sensor system associated with at least one of the object and the heating system. The sensor system may be configured to generate sensor data during curing of the workpiece.

The apparatus may include a power system configured to supply power to at least one of the heating system, the vacuum system and the control system.

The retaining structure of the portable structure may include an opening configured to receive and hold the object and may further include a seal configured to seal an interface between the object and an edge of the opening of the retaining structure.

The disclosure also describes a method for curing a workpiece to form a part. The method involves placing the workpiece over an object having a shape selected for the part and positioning the object relative to a retaining structure configured to hold the object. The retaining structure has a first side and a second side. The method also involves positioning a heating system relative to the retaining structure such that the heating system covers the object at the first side of the retaining structure and at the second side of the retaining structure. Positioning the heating system relative to the retaining structure involves positioning a first heating device over the object at the first side of the retaining structure and positioning a second heating device over the object at the second side of the retaining structure. At least one of the first and the second heating device is comprised of a deformable material. The method also involves applying a vacuum within a vacuum boundary around the object using a vacuum system. The vacuum is used in curing the workpiece to form the part and at least one of the first heating device and the second heating device deforms in response to the vacuum to conform to the shape of the object. The method also involves curing the workpiece to form the part using heat generated by the heating system.

Applying the vacuum within the vacuum boundary around the object may involve applying the vacuum within the vacuum boundary around the object using a number of vacuum ports associated with at least one of the object and the retaining structure.

The method may involve generating sensor data during curing of the workpiece using a sensor system and controlling vacuum pressure generated by the vacuum system to apply the vacuum and an amount of the heat generated by the heating system based on the sensor data generated by the sensor system, using a control system.

The method may involve supplying power to at least one of the heating system, the vacuum system and the control system using a power system.

The method may involve sealing an interface between the object and an edge of an opening in the retaining structure configured to receive the object using a seal.

Curing the workpiece to form the part using the heat generated by the heating system may involve curing a composite workpiece to form a composite part using the heat generated by the heating system. The composite part may have a final shape that substantially matches at least a portion of the shape of the object.

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

BRIEF DESCRIPTION OF THE DRAWINGS

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

Figure 1 is an illustration of a curing environment in the form of a block diagram in which an illustrative embodiment may be implemented;

Figure 2 is an illustration of a top isometric view of a portable structure in accordance with an illustrative embodiment;

Figure 3 is an illustration of a top isometric view of a mandrel in accordance with an illustrative embodiment;

Figure 4 is an illustration of a bottom isometric view of a mandrel in accordance with an illustrative embodiment;

Figure 5 is an illustration of a top isometric view of a composite workpiece laid over a mandrel in accordance with an illustrative embodiment;

Figure 6 is an illustration of a top isometric view of a thermal blanket in accordance with an illustrative embodiment;

Figure 7 is an illustration of a top isomeric view of a thermal bladder in accordance with an illustrative embodiment;

Figure 8 is an illustration of an exploded top isometric view of a curing assembly in accordance with an illustrative embodiment;

Figure 9 is an illustration of a top isometric view of a curing assembly fully assembled in accordance with an illustrative embodiment;

Figure 10 is an illustration of a bottom isometric view of a curing assembly fully assembled from in accordance with an illustrative embodiment;

Figure 11 is an illustration of a portable curing system in accordance with an illustrative embodiment;

Figure 12 is an illustration of a mandrel in accordance with an illustrative embodiment;

Figure 13 is an illustration of a process for curing a composite workpiece to form a composite part in the form of a flowchart in accordance with an illustrative embodiment;

Figure 14 is an illustration of an aircraft manufacturing and service method in the form of a block diagram in accordance with an illustrative embodiment; and

Figure 15 is an illustration of an aircraft in the form of a block diagram in accordance with an illustrative embodiment.

DETAILED DESCRIPTION

The illustrative embodiments recognize and take into account different considerations. For example, without limitation, the illustrative embodiments recognize and take into account that it may be desirable to have a curing system that is portable. In particular, it may be desirable to have a curing system that can be moved to different locations with a desired level of ease and efficiency.

Additionally, the illustrative embodiments recognize and take into account that the cost of operating some currently available curing devices may be greater than desired due to the amount of energy consumed during the operation. The illustrative embodiments recognize and take into account that a curing system that requires less energy to reach specified temperatures and specified pressure levels as compared to some currently available curing devices may reduce the costs associated with curing devices.

Thus, the illustrative embodiments may provide an apparatus and method for curing a composite workpiece to form a composite part. In particular, the illustrative embodiments may provide a portable curing system that is energy efficient.

In one illustrative embodiment, an apparatus may comprise an object, a retaining structure, and a heating system. The object may have a shape selected for a part. The portable structure may comprise a retaining structure configured to hold the object. The retaining structure may have a first side and a second side. The heating system may be configured to cover the object at the first side of the retaining structure and at the second side of the retaining structure. The heating system may be further configured to generate heat for use in curing a workpiece placed over the object to form the part.

With reference now to the figures and, in particular, with reference to **Figure 1**, an illustration of a curing environment in the form of a block diagram is depicted in accordance with an illustrative embodiment. In **Figure 1**, curing environment **100** may be an example of an environment in which workpiece **102** may be cured to form part **104**. In particular, curing system **106** may be used to cure workpiece **102** to form part **104**.

In these illustrative examples, workpiece **102** may take the form of composite workpiece **108**. Composite workpiece **108** may be comprised of any number of composite materials. These composite materials may include, for example, without limitation, at least one of a fiber reinforced polymer (FRP), a carbon-fiber reinforced plastic (CFRP), a thermoplastic, and some other suitable type of composite material. In some cases, composite workpiece **108** may comprise at least one other type of material in addition to the one or more composite materials that form composite workpiece **108**.

As used herein, the phrase “at least one of”, when used with a list of items, means 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, without limitation, “at least one of item A, item B, and item C” may include, 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 other examples, “at least one of” may be, for example, without limitation, two of item A, one of item B, and ten of item C; four of item B and seven of item C; or some other suitable combination.

In these illustrative examples, curing system **106** may be configured to use heat **110** and vacuum pressure **112** to cure composite workpiece **108**. In other illustrative examples, some other type of pressure may be used to cure composite workpiece **108** in addition to and/or in place of vacuum pressure **112**. Further, in these examples, curing system **106** may be portable curing system **114**. Portable curing system **114** may be moved to different locations with a desired level of ease and without requiring more time and/or expense than desired.

Composite workpiece **108** may be placed over object **115** such that composite workpiece **108** substantially conforms to shape **116** of object **115**. In particular, object **115** may have first surface **118** and second surface **120**. Shape **116** may be the shape of first surface **118** of object **115** in these illustrative examples.

Shape **116** may be selected based on final shape **119** desired for part **104**. Final shape **119** may be formed by at least a portion of shape **116**. For example, without limitation, when shape **116** is a cuboidal shape, final shape **119** may be only a top half portion of the cuboidal shape. In some illustrative examples, object **115** may be referred to as a tool or a mandrel.

Composite workpiece **108** may be placed over first surface **118** of object **115** such that composite workpiece **108** substantially conforms to shape **116** of object **115**. Thereafter, portable curing system **114** may be used to cure composite workpiece **108** on object **115** such that composite workpiece **108** hardens having final shape **119** to form part **104**.

As depicted, portable curing system **114** may include portable structure **121**, heating system **122**, vacuum system **124**, control system **126**, and power system **128**. Portable structure **121** may comprise retaining structure **130**. Retaining structure **130** may be configured to hold object **115** in place.

Retaining structure **130** may have first side **131** and second side **132**. In some illustrative examples, first side **131** of retaining structure **130** may be a top side or top surface of retaining structure **130**, while second side **132** may be a bottom side or bottom surface of retaining structure **130**.

In one illustrative example, retaining structure **130** may have opening **134** that extends from first side **131** to second side **132**. In particular, retaining structure **130** may be configured to receive object **115** into opening **134**. Further, retaining structure **130** may hold object **115** within opening **134** such that first surface **118** of object **115** is exposed at first side **131** of retaining structure **130** and second surface **120** of object **115** is exposed at second side **132** of retaining structure **130**.

In some cases, seal **136** may be used to seal the interface between retaining structure **130** and object **115**. In particular, seal **136** may be used to seal edge **137** of opening **134** in retaining structure **130** such that fluids, including air and/or other types of gases, are not allowed to pass through opening **134** once object **115** is held in place by retaining structure **130**. Seal **136** may take a number of different forms and comprise any number of components. For example, without limitation, seal **136** may be a gasket.

As depicted, portable structure **121** may also include support structure **138** in some illustrative examples. Support structure **138** may be configured to support retaining structure **130** such that retaining structure **130** is held at some distance from surface **140** on which portable curing system **114** is being used. Surface **140** may be, for example, without limitation, a table surface, a floor, a platform surface, or some other type of surface.

Heating system **122** may be configured to generate heat **110** for use in curing composite workpiece **108**. Heating system **122** may be configured to surround object **115**. In particular, heating system **122** may be configured to cover object **115** at first side **131** of retaining structure **130** and second side **132** of retaining structure **130**. As one illustrative example, heating system **122** may comprise first heating device **142** and second heating device **144**.

First heating device **142** may be positioned relative to first surface **118** of object **115** with composite workpiece **108** on first surface **118**. In this manner, first heating device **142** may cover object **115** at first side **131** of retaining structure **130**. More specifically, first heating device **142** may cover composite workpiece **108** lying on first surface **118** of object **115**. Further, second heating device **144** may be positioned relative to second surface **120** of object **115** such that second heating device **144** covers second surface **120** of object **115** at second side **132** of retaining structure **130**.

First heating device **142** and second heating device **144** may be configured to generate heat **110** to increase the temperature of object **115** and composite workpiece **108** on object **115**. The temperature of object **115** and composite workpiece **108** may be increased to a temperature specified for the curing of composite workpiece **108**.

Additionally, vacuum system **124** may be configured to apply vacuum **146** for use in curing composite workpiece **108**. In one illustrative example, number of vacuum ports **148** may be associated with at least one of object **115** and portable structure **121**. Vacuum system **124** may connect to number of vacuum ports **148** using number of vacuum lines **152**.

As used herein, when one component is "associated" with another component, this association is a physical association in the depicted examples. For example, without limitation, a first component, such as one of number of vacuum ports **148**, may be considered to be associated with a second component, such as portable structure **121**, by being secured to the second component, bonded to the second component, mounted to the second component, welded to the second component, fastened to the second component, and/or connected to the second component in some other suitable manner.

Additionally, the first component also may be connected to the second component 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 as an extension of the second component.

In this illustrative example, vacuum system **124** may apply vacuum **146** within vacuum boundary **154** around object **115**. Vacuum boundary **154** may be formed by at least one of heating system **122**, vacuum bag **156**, and some other suitable type of structure and/or material. For example, without limitation, vacuum bag **156** may be placed around portable structure **121** and around heating system **122**. Vacuum bag **156** may be substantially hermetic in this example.

Vacuum system **124** may remove gas molecules from the space within vacuum boundary **154** through number of vacuum lines **152** connected to number of vacuum ports **148**. Removing gas molecules from this space may apply vacuum **146** within vacuum boundary **154**. Vacuum **146** may aid in the curing of composite workpiece **108**. In some cases, vacuum **146** may reduce the porosity of part **104** formed by the curing process.

Additionally, in some cases, at least one of first heating device **142** and second heating device **144** may be configured to deform in response to vacuum **146**. For example, without limitation, at least one of first heating device **142** and second heating device **144** may be comprised of deformable material **158**. Deformable material **158** may be selected such that first heating device **142** and/or second heating device **144** may deform in response to vacuum **146** generated by vacuum system **124**.

For example, without limitation, when first heating device **142** is comprised of deformable material **158**, first heating device **142** may deform to substantially conform to shape **116** of object **115** in response to vacuum **146** being applied. In this manner, heat **110** generated by first heating device **142** may be more directly applied to first surface **118** of object **115** during curing. This type of application of heat **110** may reduce the amount of energy consumed to reach the temperatures specified for the curing of composite workpiece **108**.

In these illustrative examples, control system **126** may be configured to control at least one of heating system **122** and vacuum system **124**. In particular, control system **126** may control vacuum pressure **112** generated by vacuum system **124** to apply vacuum **146** and amount **162** of heat **110** generated by heating system **122**.

In one illustrative example, control system **126** may use sensor data **164** generated by sensor system **166** to control heating system **122** and/or vacuum system **124**. Sensor system **166** may comprise any number of sensors, such as, for example, without limitation, temperature sensors, pressure sensors, and other types of sensors. Sensor system **166** may monitor at least one of the temperatures of the different components within portable curing system **114** and the vacuum pressure within vacuum boundary **154** during the curing of composite workpiece **108**.

As one illustrative example, sensor system **166** may comprise one or more thermocouples. These thermocouples may be attached to at least one of object **115**, heating system **122**, composite workpiece **108**, or some other component of portable curing system **114**. These thermocouples may be used to generate sensor data **164** in the form of temperature data **168**. Control system **126** may use this temperature data **168** to adjust amount **162** of heat **110** generated by first heating device **142** and/or second heating device **144** in heating system **122** during the curing of composite workpiece **108**.

Control system **126** may be implemented in, for example, without limitation, computer system **169** comprising one or more computers. In some cases, control system **126** may be implemented in, for example, without limitation, a laptop, a processor unit, a personal digital assistant (PDA), or some other type of computer hardware. Control system **126** may have a size and weight configured such that control system **126** is portable.

Power system **128** may be configured to supply power **170** to at least one of heating system **122**, vacuum system **124**, and control system **126**. Power system **128** may comprise any number of power sources. For example, without limitation, power system **128** may include a power generator, a battery system, a motor, and/or other types of power devices.

In this manner, portable curing system **114** may be used to cure composite workpiece **108** to form part **104**. In particular, part **104** may be referred to as composite part **172**. Composite part **172** may have final shape **119**. With this type of portable curing system, different types of objects may be used to form parts having different shapes. In this manner, portable curing system **114**, in addition to being portable, may be adaptable such that different types of parts may be formed using portable curing system **114**.

The illustration of curing environment in **Figure 1** is not meant to imply physical or architectural limitations to the manner in which an illustrative embodiment may be implemented. Other components in addition to or in place of the ones illustrated may be used. Some components may be optional. Also, the blocks may be presented to illustrate some functional components. One or more of these blocks may be combined, divided, or combined and divided into different blocks when implemented in an illustrative embodiment.

In some illustrative examples, second surface **120** of object **115** may not be left exposed. In other illustrative examples, other components in addition to and/or in place of the ones described above may be included in portable curing system **114**. In some cases, support structure **138** may be optional for portable structure **121**.

In still other illustrative examples, a first breather material (not shown) and a second breather material (not shown) may be used. The first breather material (not shown) may be positioned between first heating device **142** and retaining structure **130**. In this manner, the first breather material (not shown) may cover composite workpiece **108** lying on first surface **118** of object **115** at first side **131** of retaining structure **130**, while first heating device **142** may cover the first breather material (not shown).

Additionally, the second breather material (not shown) may be positioned between second heating device **144** and retaining structure **130**. In this manner, the second breather material (not shown) may cover second surface **120** of object **115** at second side **132** of retaining structure **130**.

The first breather material (not shown) and the second breather material (not shown) may be used to help apply vacuum **146** within vacuum boundary **154**. In particular, these breather materials (not shown) may be comprised of materials such as, for example, without limitation, wool, cotton, or some other type of fabric configured to allow air to move through the breather materials.

With reference now to **Figure 2**, an illustration of a top isometric view of a portable structure is depicted in accordance with an illustrative embodiment. In **Figure 2**, portable structure **200** may be an example of one implementation for portable structure **121** in **Figure 1**. As depicted, portable structure **200** may include retaining structure **202** and support structure **204**. Retaining structure **202** and support structure **204** may be examples of implementations for retaining structure **130** and support structure **138**, respectively, in **Figure 1**.

In this illustrative example, support structure **204** may support retaining structure **202**. In particular, retaining structure **202** may have first side **206** and second side **208**. In this illustrative example, first side **206** may be a top side of retaining structure **202**, while second side **208** may be a bottom side of retaining structure **202**.

Further, support structure **204** may have first side **210** and second side **212**. In this illustrative example, first side **210** may be a top side of support structure **204**, while second side **212** may be a bottom side of support structure **204**. As depicted, retaining structure **202** may be attached to first side **210** of support structure **204**.

Further, retaining structure **202** may have opening **214**. Opening **214** may be configured to receive an object, such as, for example, without limitation, object **115** in **Figure 1**. Additionally, support structure **204** may have access openings **216**. Access openings **216** may be configured to provide an operator with access to opening **214** of retaining structure **202** at second side **208** of retaining structure **202**.

As depicted, vacuum attachment point **218** and vacuum attachment point **220** may be attachment points for vacuum ports (not shown) on retaining structure **202** of portable structure **200**. In particular, vacuum attachment point **218** and vacuum attachment point **220** may be located on first side **206** of retaining structure **202**.

Turning now to **Figure 3**, an illustration of a top isometric view of a mandrel is depicted in accordance with an illustrative embodiment. In **Figure 3**, object **300** may be an example of one implementation for object **115** in **Figure 1**. In this illustrative example, object **300** may take the form of mandrel **301**. In particular, mandrel **301** may be considered a male mandrel.

As depicted, mandrel **301** may have first portion **302** and second portion **304**. Second portion **304** may be the portion of mandrel **301** used for shaping a workpiece (not shown) during curing. Further, mandrel **301** may have first surface **306** and second surface **308**. First surface **306** may have shape **310**. In particular, shape **310** may be the shape of first surface **306** of second portion **304** of mandrel **301**. Shape **310** may be an example of one implementation for shape **116** in **Figure 1**.

In this illustrative example, mandrel **301** may have plurality of holes **312**. These holes may be used to attach mandrel **301** to retaining structure **202** of portable structure **200** in **Figure 2**. In particular, fasteners (not shown) may be inserted into plurality of holes **312** to attach mandrel **301** to first side **206** of retaining structure **202** of portable structure **200** in **Figure 2**.

As depicted, mandrel **301** may have cut corner **314** and cut corner **316**. Cut corner **314** and cut corner **316** may be configured such that vacuum attachment point **218** and vacuum attachment point **220** on retaining structure **202** in **Figure 2** may remain exposed when mandrel **301** is attached to retaining structure **202**.

With reference now to **Figure 4**, an illustration of a bottom isometric view of mandrel **301** from **Figure 3** is depicted in accordance with an illustrative embodiment. As depicted in **Figure 4**, shape **310** of first surface **306** of second portion **304** of mandrel **301** may form cavity **400** with respect to second surface **308** of mandrel **301**.

Turning now to **Figure 5**, an illustration of a top isometric view of a composite workpiece laid over mandrel **301** from **Figure 3** is depicted in accordance with an illustrative embodiment. In **Figure 5**, composite workpiece **500** may be placed over mandrel **301**. Composite workpiece **500** may be an example of one implementation for composite workpiece **108** in **Figure 1**.

As depicted, composite workpiece **500** may be placed over first surface **306** of second portion **304** of mandrel **301** such that composite workpiece **500** substantially conforms to shape **310**. In this illustrative example, composite workpiece **500** may cover only a portion of shape **310** of mandrel **301**. Consequently, final shape **502** of composite workpiece **500** may be formed by only a portion of shape **310** of mandrel **301**. Final shape **502** may be the final shape for the composite part to be formed by curing composite workpiece **500**.

With reference now to **Figure 6**, an illustration of a top isometric view of a thermal blanket is depicted in accordance with an illustrative embodiment. In **Figure 6**, heating device **600** may be an example of one implementation for first heating device **142** in **Figure 1**. In this illustrative example, heating device **600** may take the form of thermal blanket **601**. As depicted, thermal blanket **601** may have first side **602** and second side **604**.

With reference now to **Figure 7**, an illustration of a top isomeric view of a thermal bladder is depicted in accordance with an illustrative embodiment. In **Figure 7**, heating device **700** may be an example of one implementation for second heating device **144** in **Figure 1**. In this illustrative example, heating device **700** may take the form of thermal bladder **701**. As depicted, thermal bladder **701** may have first side **702** and second side **704**.

Turning now to **Figure 8**, an illustration of an exploded top isometric view of a curing assembly is depicted in accordance with an illustrative embodiment. In **Figure 8**, curing assembly **800** may be formed using portable structure **200** from **Figure 2**, mandrel **301** from **Figures 3-5**, thermal blanket **601** from **Figure 6**, thermal bladder **701** from **Figure 7**, and gasket **801**.

Gasket **801** may be an example of one implementation for seal **136** in **Figure 1**. Additionally, number of vacuum ports **802** may be considered part of a curing assembly **800** in this illustrative example. As depicted, number of vacuum ports **802** may include vacuum ports **804**, **806**, **808** and **810**.

Vacuum port **804** and vacuum port **806** may be attached to vacuum attachment point **218** and vacuum attachment point **220**, respectively, on first side **206** of retaining structure **202** of portable structure **200**. Further, vacuum port **808** and vacuum port **810** may be attached to vacuum attachment points (not shown) on first surface **306** of mandrel **301** when curing assembly **800** is assembled.

Additionally, first breather material **812** and second breather material **814** may also be used to form curing assembly **800**. First breather material **812** may be positioned between thermal blanket **601** and mandrel **301**. Second breather material **814** may be positioned between thermal bladder **701** and mandrel **301**. First breather material **812** and second breather material **814** may be comprised of, for example, without limitation, wool. The wool may allow air to pass through these breather materials when a vacuum is applied using number of vacuum ports **802**.

With reference now to **Figure 9**, an illustration of a top isometric view of curing assembly **800** from **Figure 8** fully assembled is depicted in accordance with an illustrative embodiment. As depicted, thermal blanket **601** may cover first surface **306** of mandrel **301** at first side **206** of retaining structure **202**. Thermal blanket **601** and thermal bladder **701** (hidden in this view) may together form heating system **900**. Heating system **900** may be an example of one implementation for heating system **122 in Figure 1.**

First breather material **812** and second breather material **814** from **Figure 8** may not be shown in this view in **Figure 9**. In particular, first breather material **812** and second breather material **814** from **Figure 8** may be covered by thermal blanket **601** and thermal bladder **701**, respectively.

With reference now to **Figure 10**, an illustration of a bottom isometric view of curing assembly **800** fully assembled from **Figure 9** is depicted in accordance with an illustrative embodiment. In **Figure 10**, thermal bladder **701** may be more clearly seen. Thermal bladder **701** may cover second surface **308** of mandrel **301** at second side **208** of retaining structure **202**.

With reference now to **Figure 11**, an illustration of a portable curing system is depicted in accordance with an illustrative embodiment. In **Figure 11**, portable curing system **1100** may include curing assembly **800** from **Figure 9** fully assembled, heating system **900**, vacuum bag **1102**, portable console **1104**, and control system **1106**.

In this illustrative example, portable console **1104** may include a vacuum system (not shown) and a power system (not shown). This vacuum system (not shown) and power system (not shown) may be implemented using vacuum system **124** and power system **128**, respectively, described in **Figure 1**.

Vacuum bag **1102** may be placed around curing assembly **800**. Vacuum bag **1102** may substantially hermetically seal the space within vacuum bag **1102** such that a vacuum may be applied within vacuum bag **1102**. This vacuum may be generated by the vacuum system (not shown) removing gas molecules from within vacuum bag **1102** through number of vacuum lines **1108** connected to number of vacuum ports **802**. Number of vacuum lines **1108** may include vacuum lines **1110**, **1112**, **1114**, and **1116** connected to vacuum ports **804**, **806**, **808**, and **810**, respectively.

Further, control system **1106** may be used to control the vacuum pressure generated by the vacuum system (not shown) within vacuum bag **1102**. Control system **1106** may be also used to control the amount of heat generated by heating system **900**. In this manner, the curing performed by the vacuum applied by the vacuum system and the heat provided by heating system **900** may be monitored and adjusted during the curing process as needed.

With reference now to **Figure 12**, an illustration of a mandrel is depicted in accordance with an illustrative embodiment. Mandrel **1200** may an example of one implementation for object **115** in **Figure 1**. As depicted, mandrel **1200** may have first portion **1202** and second portion **1204**. Second portion **1204** may have shape **1206**. Shape **1206** may be different from shape **310** of mandrel **301** in **Figure 1**.

Depending on the implementation, mandrel **1200** may be used in curing assembly **800** in **Figures 8-11** instead of mandrel **301**. With mandrel **301**, the part (not shown) formed by curing a composite workpiece (not shown) laid over second portion **1204** of mandrel **1200** may be different from the shape of the part (not shown) formed by curing composite workpiece **500** laid over mandrel **301** in **Figure 5**.

The illustrations of portable structure **200** in **Figure 2**, mandrel **301** in **Figures 3-5**, thermal blanket **601** in **Figure 6**, thermal bladder **701** in **Figure 7**, curing assembly **800** in **Figures 8-11**, portable curing system **1100** in **Figure 11**, and mandrel **1200**, are not meant to imply physical or architectural limitations to the manner in which an illustrative embodiment may be implemented. Other components in addition to or in place of the ones illustrated may be used. Some components may be optional.

The different components shown in **Figures 2-12** may be illustrative examples of how components shown in block form in **Figure 1** may be implemented as physical structures. Additionally, the different components shown in **Figures 2-12** may be combined with components in **Figure 1**, used with components in **Figure 1**, or a combination of the two.

With reference now to **Figure 13**, an illustration of a process for curing a composite workpiece to form a composite part in the form of a flowchart is depicted in accordance with an illustrative embodiment. The process illustrated in **Figure 13** may be implemented using portable curing system **114** in **Figure 1**. Further, this process may be implemented to cure composite workpiece **108** to form composite part **172** having final shape **119** in **Figure 1**.

The process may begin by placing composite workpiece **108** over object **115** having shape **116** selected for composite part **172** (operation **1300**). Object **115** may be positioned relative to retaining structure **130** of portable structure **121** (operation **1302**). In operation **1302**, retaining structure **130** may be configured to hold object **115** within opening **134** in retaining structure **130**. Retaining structure **130** may have first side **131** and second side **132**.

Then, first heating device **142** may be positioned relative to retaining structure **130** such that first heating device **142** covers object **115** at first side **131** of retaining structure **130** (operation **1304**). In some illustrative examples, a first breather material, such as, for example, without limitation, first breather material **812** in **Figure 8**, may be positioned relative to retaining structure **130** at first side **131** of retaining structure **130** prior to first heating device **142** being positioned relative to retaining structure **130**. In this manner, first heating device **142** may cover both the first breather material and object **115**.

Second heating device **144** may be positioned relative to retaining structure **130** such that second heating device **144** covers object **115** at second side **132** of retaining structure **130** (operation **1306**). In some illustrative examples, a second breather material, such as, for example, without limitation, second breather material **814** in **Figure 8**, may be positioned relative to retaining structure **130** at second side **132** of retaining structure **130** prior to second heating device **144** being positioned relative to retaining structure **130**. In this manner, second heating device **144** may cover both the second breather material and object **115**.

An interface between object **115** and edge **137** of opening **134** in retaining structure **130** may be sealed using seal **136** (operation **1308**). Seal **136** may substantially hermetically seal this interface in operation **1308**.

Thereafter, vacuum **146** may be applied within vacuum boundary **154** around object **115** using vacuum system **124** and number of vacuum ports **148** associated with at least one of object **115** and retaining structure **130** (operation **1310**). Composite workpiece **108** may be cured to form composite part **172** using at least one of heat **110** generated by first heating device **142** and second heating device **144** and vacuum **146** applied by vacuum system **124** (operation **1312**).

Further, composite workpiece **108** may be monitored by generating sensor data **164** during the curing of composite workpiece **108** using sensor system **166** (operation **1314**). Control system **126** may determine whether vacuum pressure **112** generated by vacuum system **124** to apply vacuum **146** and/or amount **162** of heat **110** generated by first heating device **142** and second heating device **144** need to be adjusted based on sensor data **164** (operation **1316**). If vacuum pressure **112** and/or heat **110** need to be adjusted, control system **126** may control heating system **122** to adjust heat and/or vacuum system **124** to adjust vacuum pressure **112** (operation **1318**).

The process may determine whether the curing of composite workpiece **108** has been completed (operation **1320**). If the curing of composite workpiece **108** has been completed, the process may terminate. The result of the curing process may be composite part **172** having final shape **119**.

With reference again to operation **1320**, if the curing of composite workpiece **108** has not been completed, the process may return to operation **1314**. With reference again to operation **1316**, if vacuum pressure **112** and/or heat **110** do not need to be adjusted, the process may proceed to operation **1320** as described above.

The flowcharts and block diagrams in the different depicted embodiments may illustrate the architecture, functionality, and operation of some possible implementations of apparatus and methods in an illustrative embodiment. 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.

In some alternative implementations of an illustrative embodiment, the function or functions noted in the blocks may occur out of the order noted in the figures. For example, without limitation, in some cases, two blocks shown in succession may be executed substantially concurrently, or the blocks may sometimes be performed in the reverse order, depending upon the functionality involved. Also, other blocks may be added in addition to the illustrated blocks in a flowchart or block diagram.

Illustrative embodiments of the disclosure may be described in the context of aircraft manufacturing and service method **1400** as shown in **Figure 14** and aircraft **1500** as shown in **Figure 15**. Turning first to **Figure 14**, an illustration of an aircraft manufacturing and service method in the form of a block diagram is depicted in accordance with an illustrative embodiment. During pre-production, aircraft manufacturing and service method **1400** may include specification and design **1402** of aircraft **1500** in **Figure 15** and material procurement **1404**.

During production, component and subassembly manufacturing **1406** and system integration **1408** of aircraft **1500** in **Figure 15** may take place. Thereafter, aircraft **1500** in **Figure 15** may go through certification and delivery **1410** in order to be placed in service **1412**. While in service **1412** by a customer, aircraft **1500** in **Figure 15** may be scheduled for routine maintenance and service **1414**, which may include modification, reconfiguration, refurbishment, and other maintenance or service.

Each of the processes of aircraft manufacturing and service method **1400** 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, a leasing company, a military entity, a service organization, and so on.

With reference now to **Figure 15**, an illustration of an aircraft in the form of a block diagram is depicted in which an illustrative embodiment may be implemented. In this example, aircraft **1500** may be produced by aircraft manufacturing and service method **1400** in **Figure 14** and may include airframe **1502** with plurality of systems **1504** and interior

1506. Examples of systems **1504** may include one or more of propulsion system **1508**, electrical system **1510**, hydraulic system **1512**, and environmental system **1514**. Any number of other systems may be included. Although an aerospace example is shown, different illustrative embodiments may be applied to other industries, such as the automotive industry.

Apparatuses and methods embodied herein may be employed during at least one of the stages of aircraft manufacturing and service method **1400** in **Figure 14**.

In one illustrative example, components or subassemblies produced in component and subassembly manufacturing **1406** in **Figure 14** may be fabricated or manufactured in a manner similar to components or subassemblies produced while aircraft **1500** is in service **1412** in **Figure 14**. As yet another example, one or more apparatus embodiments, method embodiments, or a combination thereof may be utilized during production stages, such as component and subassembly manufacturing **1406** and system integration **1408** in **Figure 14**.

For example, without limitation, portable curing system **114** may be used to cure composite materials to form parts for aircraft **1500** during one or more of component and subassembly manufacturing **1406**, system integration **1408**, routine maintenance and service **1414** and other stages during the processes of aircraft manufacturing and service method **1400** in **Figure 14**. Further, portable curing system **114** may be configured to move to different locations during these different stages.

One or more apparatus embodiments, method embodiments, or a combination thereof may be utilized while aircraft **1500** is in service **1412** and/or during maintenance and service **1414** in **Figure 14**. The use of a number of the different illustrative embodiments may substantially expedite the assembly of and/or reduce the cost of aircraft **1500**.

The description of the different illustrative 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 may be apparent to those of ordinary skill in the art. Further, different illustrative embodiments may provide different features as compared to other illustrative embodiments. The embodiment or embodiments selected are chosen and described in order to best explain the principles of the embodiments, the practical application, and to enable others of ordinary skill in the art to understand the disclosure for various embodiments with various modifications as are suited to the particular use contemplated.

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

1. An apparatus comprising:

an object having a shape selected for a part;

a portable structure comprising a retaining structure configured to hold the object, the retaining structure having a first side and a second side; and

a heating system configured to cover the object at the first side of the retaining structure and the second side of the retaining structure, the heating system being configured to generate heat for use in curing a workpiece placed over the object to form the part, the heating system comprising:

a first heating device configured to cover the object at the first side of the retaining structure; and

a second heating device configured to cover the object at the second side of the retaining structure,

wherein at least one of the first heating device and the second heating device is comprised of a deformable material selected such that the at least one of the first heating device and the second heating device deforms in response to a vacuum to conform to the shape of the object.

2. The apparatus of claim **1**, further comprising:

a number of vacuum ports associated with at least one of the object and the retaining structure; and a vacuum system connected to the number of vacuum ports and configured to apply a vacuum within a vacuum boundary formed around the object in which the vacuum is used in curing the workpiece placed over the object to form the part.

3. The apparatus of claim **2**, wherein the vacuum boundary is formed by at least one of the heating system and a vacuum bag.

4. The apparatus of claim **2** or **3**, further comprising:

a control system configured to control vacuum pressure generated by the vacuum system to apply the vacuum and an amount of the heat generated by the heating system.

5. The apparatus of any one of claims **1** to **4**, further comprising:

a sensor system associated with at least one of the object and the heating system, wherein the sensor system is configured to generate sensor data during curing of the workpiece.

6. The apparatus of claim **5**, further comprising:

a power system configured to supply power to at least one of the heating system, the vacuum system and the control system.

7. The apparatus of any one of claims **1** to **6**, wherein the retaining structure of the portable structure comprises an opening configured to receive and hold the object and further comprising:

a seal configured to seal an interface between the object and an edge of the opening of the retaining structure.

8. A method for curing a workpiece to form a part, the method comprising:

placing the workpiece over an object having a shape selected for the part;

positioning the object relative to a retaining structure configured to hold the object, the retaining structure having a first side and a second side;

positioning a heating system relative to the retaining structure such that the heating system covers the object at the first side of the retaining structure and at the second side of the retaining structure, wherein positioning the heating system relative to the retaining structure comprises:

positioning a first heating device over the object at the first side of the retaining structure; and

positioning a second heating device over the object at the second side of the retaining structure, wherein at least one of the first and the second heating device is comprised of a deformable material;

applying a vacuum within a vacuum boundary around the object using a vacuum system, wherein the vacuum is used in curing the workpiece to form the part, and wherein at least one of the first heating device and the second heating device deforms in response to the vacuum to conform to the shape of the object; and curing the workpiece to form the part using heat generated by the heating system.

9. The method of claim **8**, wherein applying the vacuum within the vacuum boundary around the object comprises:

applying the vacuum within the vacuum boundary around the object using a number of vacuum ports associated with at least one of the object and the retaining structure.

10. The method of claim **8** or **9,** further comprising:

generating sensor data during curing of the workpiece using a sensor system; and

controlling vacuum pressure generated by the vacuum system to apply the vacuum and an amount of the heat generated by the heating system based on the sensor data generated by the sensor system using a control system.

11. The method of claim **10**, further comprising:

supplying power to at least one of the heating system, the vacuum system and the control system using a power system.

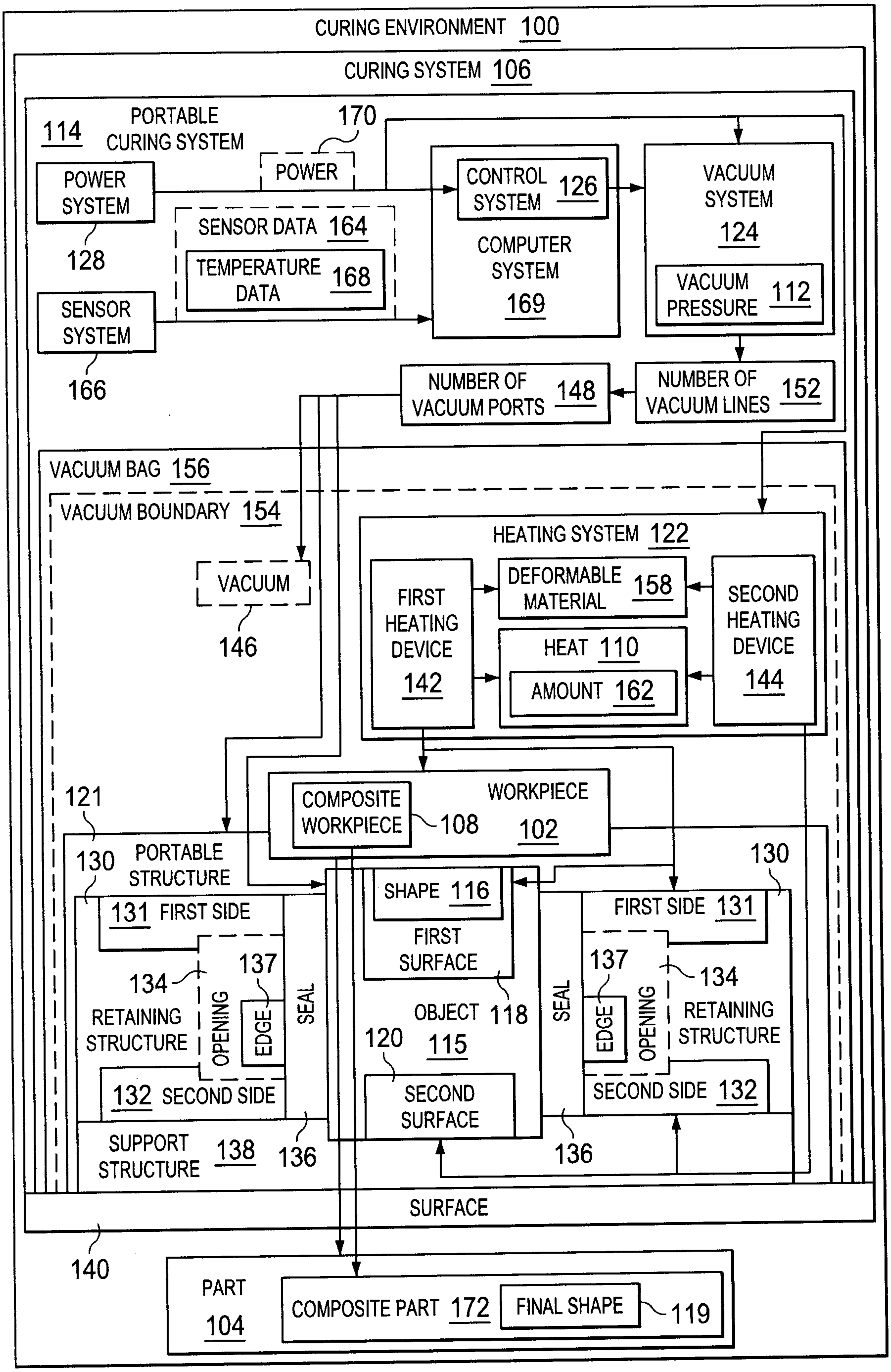
12. The method of any one of claims **8** to **11**, further comprising:

sealing an interface between the object and an edge of an opening in the retaining structure configured to receive the object using a seal.

13. The method of any one of claims **8** to **12**, wherein curing the workpiece to form the part using the heat generated by the heating system comprises:

> curing a composite workpiece to form a composite part using the heat generated by the heating system, wherein the composite part has a final shape that substantially matches at least a portion of the shape of the object.

FIG. 1


CURING ENVIRONMENT 100
CURING SYSTEM 106
114 PORTABLE CURING SYSTEM
170
POWER
POWER SYSTEM
128
SENSOR DATA 164
TEMPERATURE DATA 168
SENSOR SYSTEM
166
CONTROL SYSTEM 126
COMPUTER SYSTEM 169
VACUUM SYSTEM 124
VACUUM PRESSURE 112
NUMBER OF VACUUM PORTS 148
NUMBER OF VACUUM LINES 152
VACUUM BAG 156
VACUUM BOUNDARY 154
VACUUM
146
HEATING SYSTEM 122
FIRST HEATING DEVICE 142
DEFORMABLE MATERIAL 158
HEAT 110
AMOUNT 162
SECOND HEATING DEVICE 144
121
COMPOSITE WORKPIECE
108
WORKPIECE 102
130
PORTABLE STRUCTURE
131 FIRST SIDE
134
137
RETAINING STRUCTURE
OPENING
EDGE
SEAL
132 SECOND SIDE
SHAPE 116
FIRST SURFACE
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OBJECT 115
120
SECOND SURFACE
SUPPORT STRUCTURE 138
136
SURFACE
140
PART 104
COMPOSITE PART 172
FINAL SHAPE
119

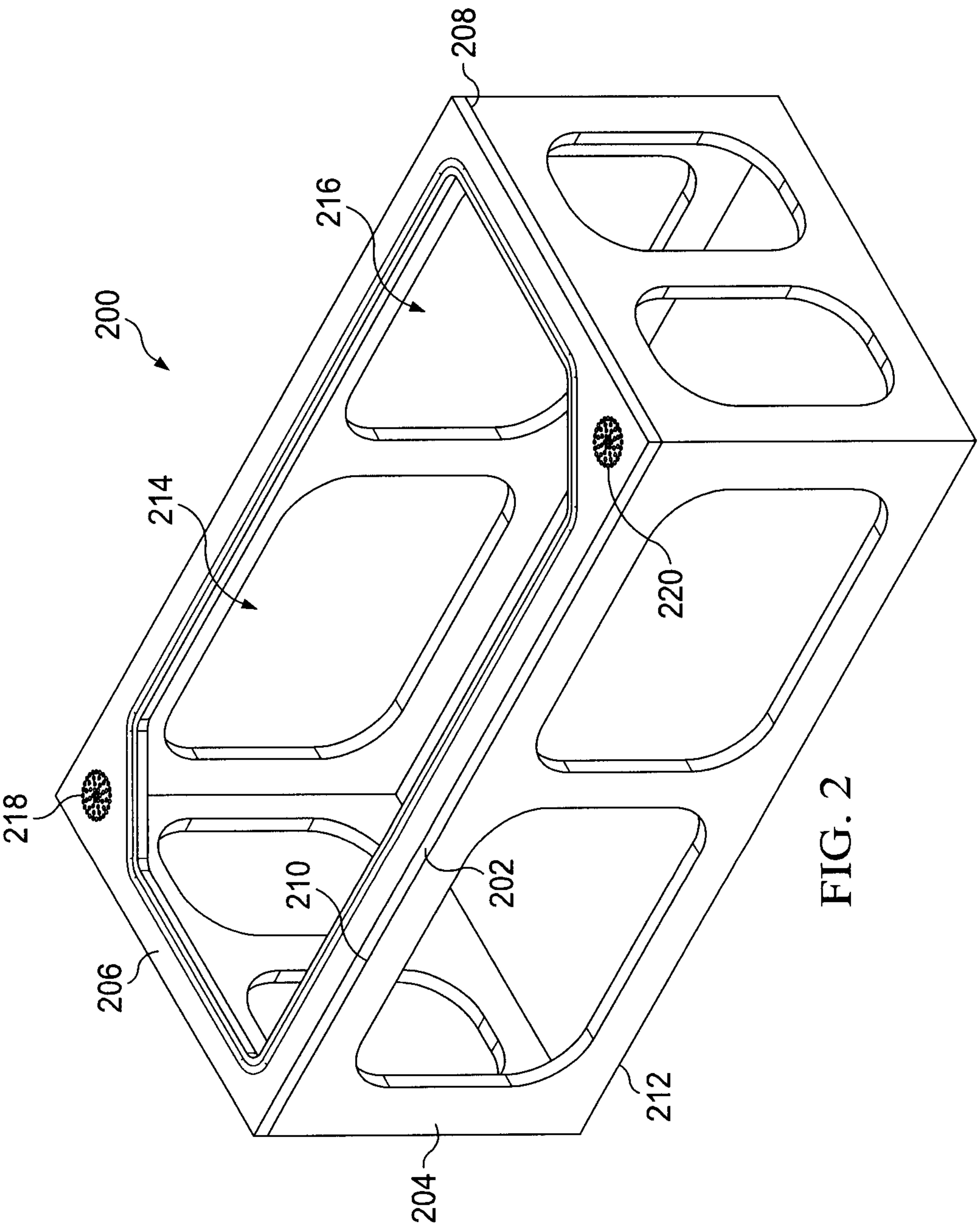


FIG. 2

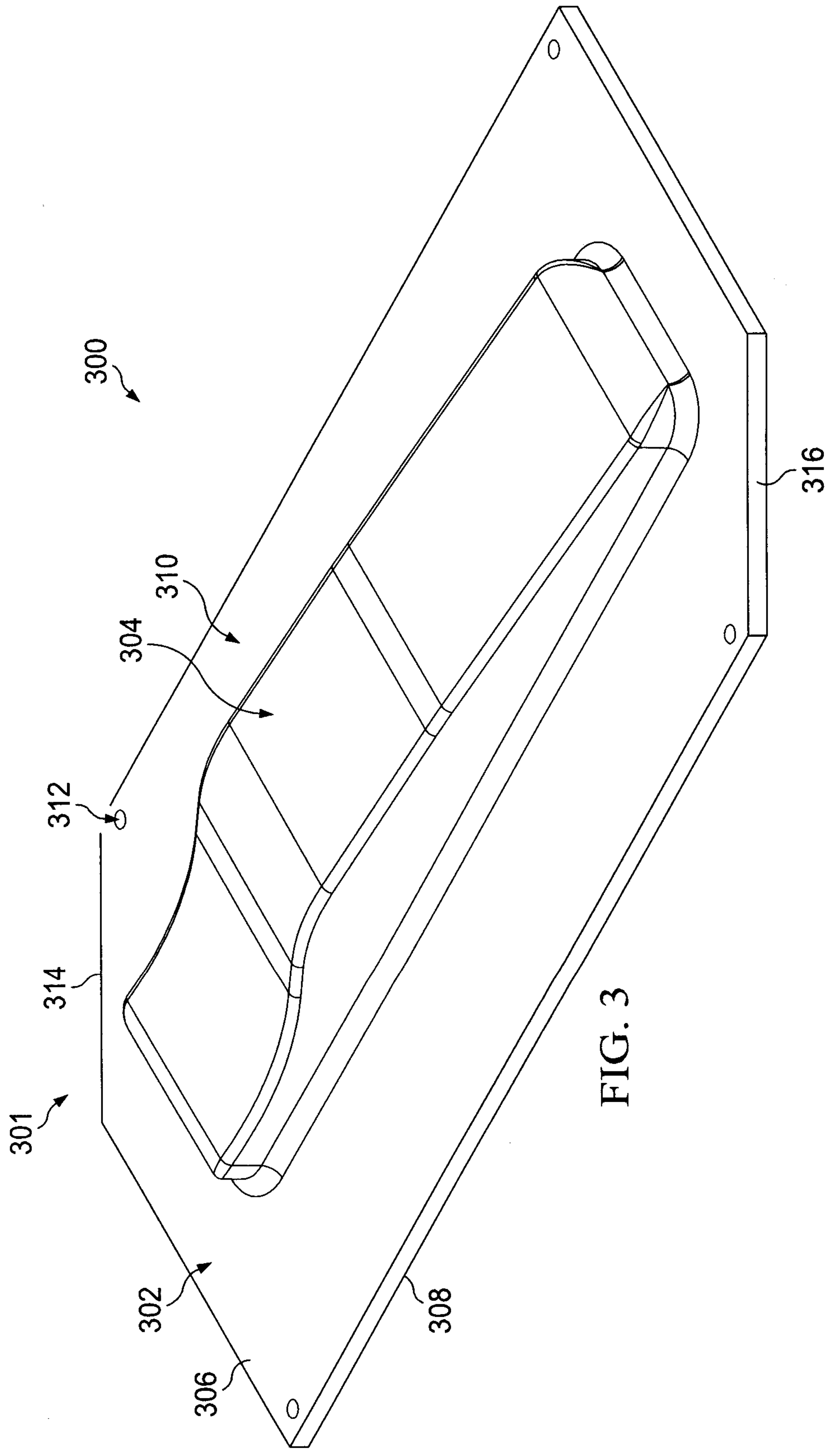


FIG. 3

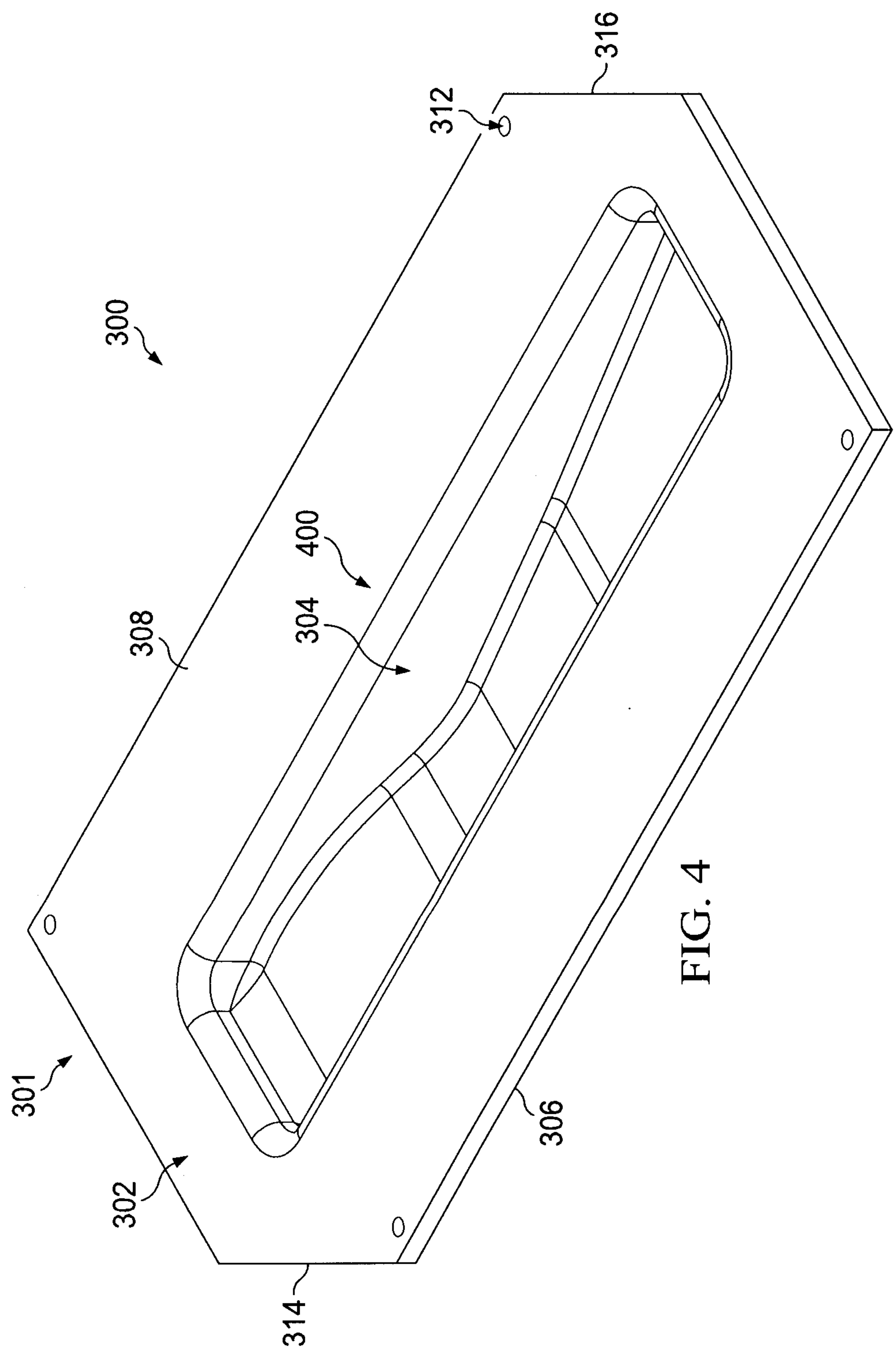


FIG. 4

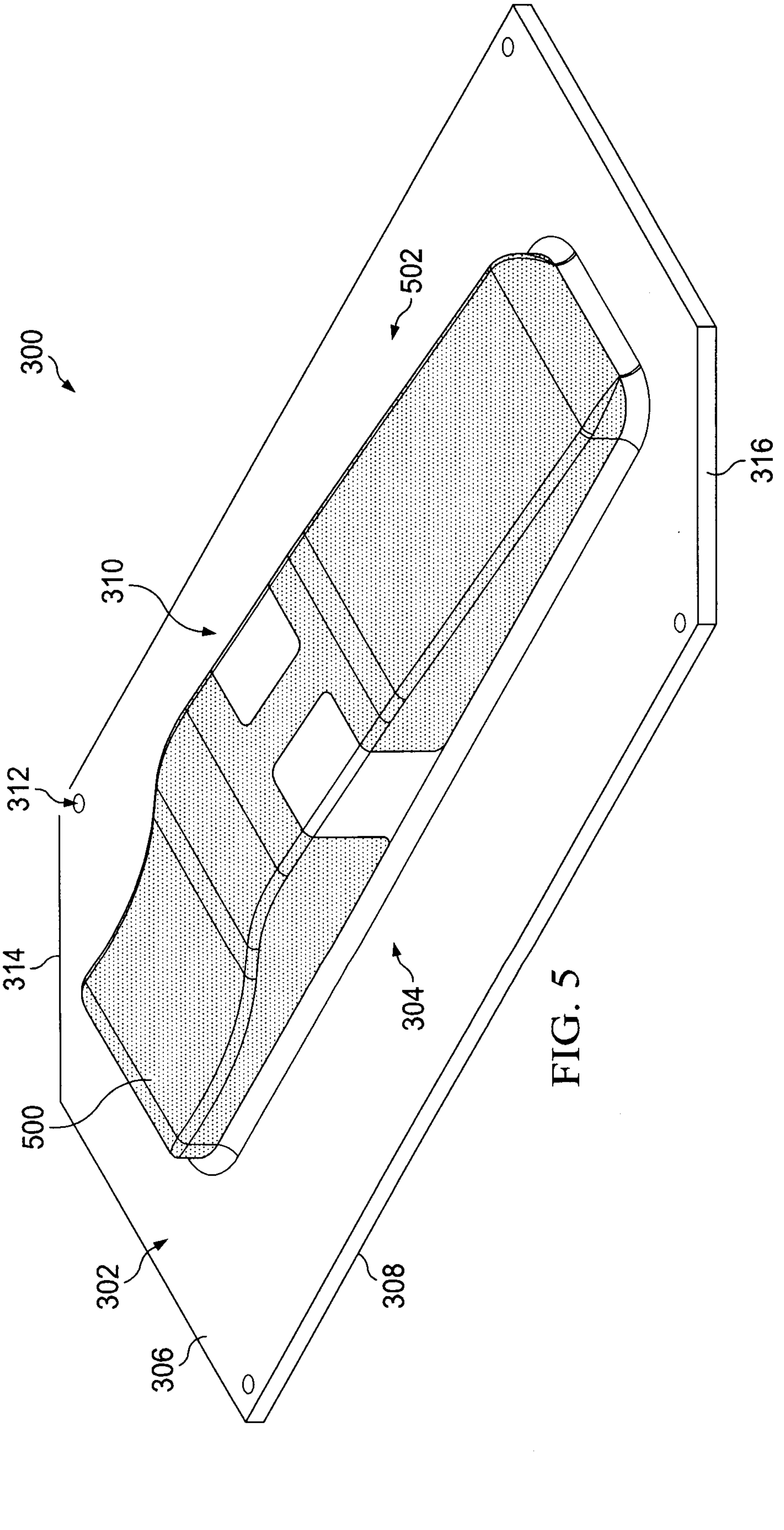


FIG. 5

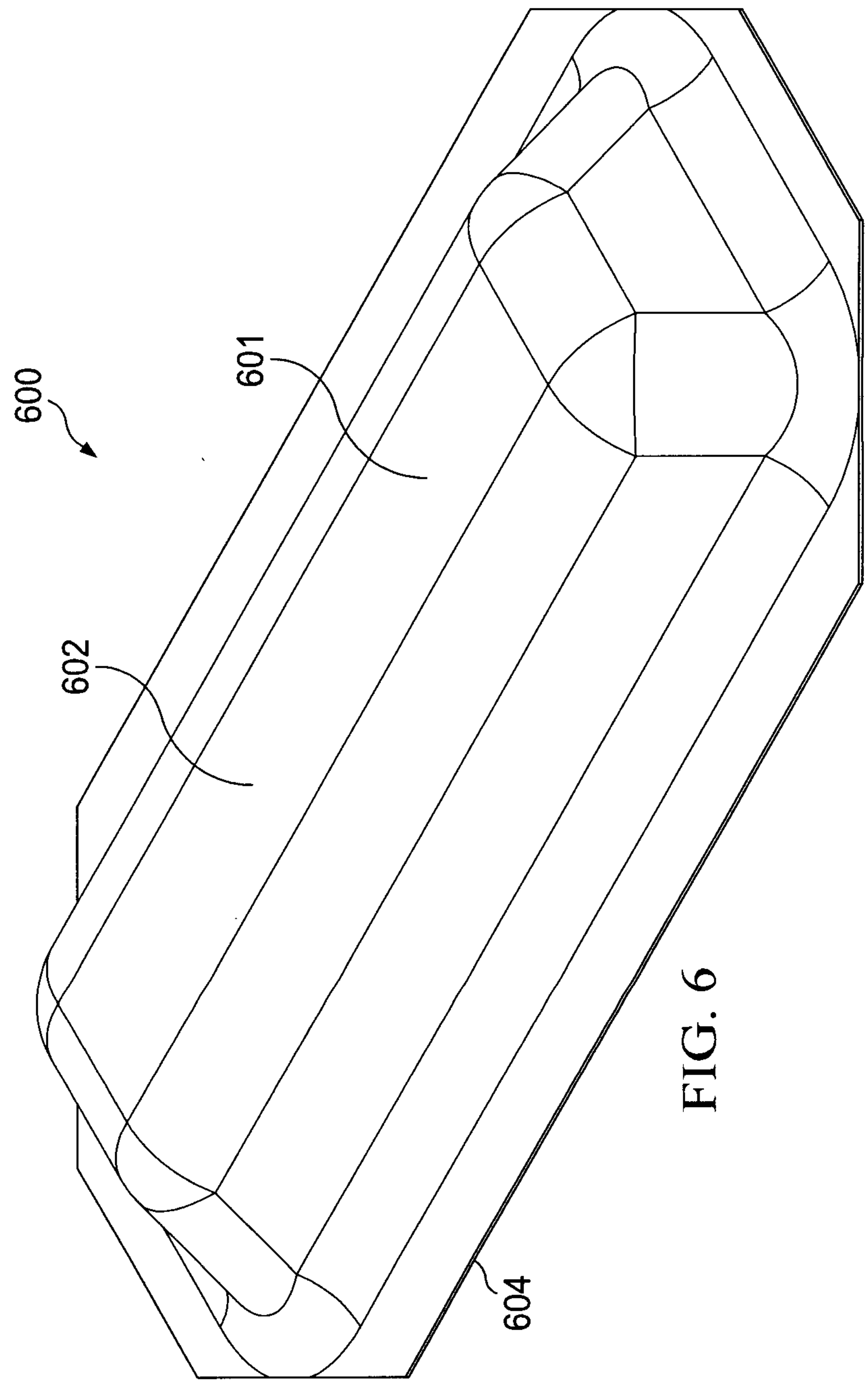


FIG. 6

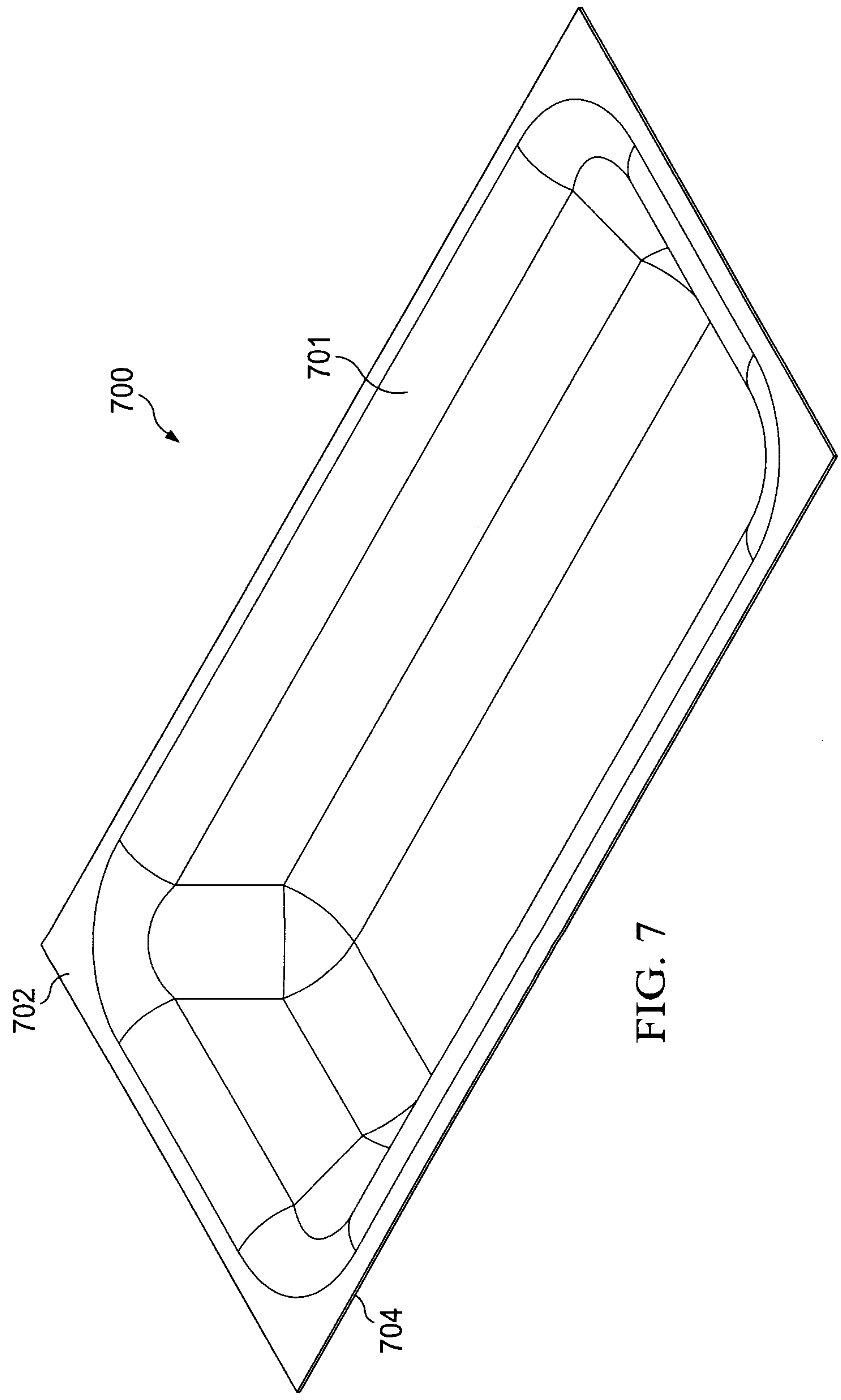
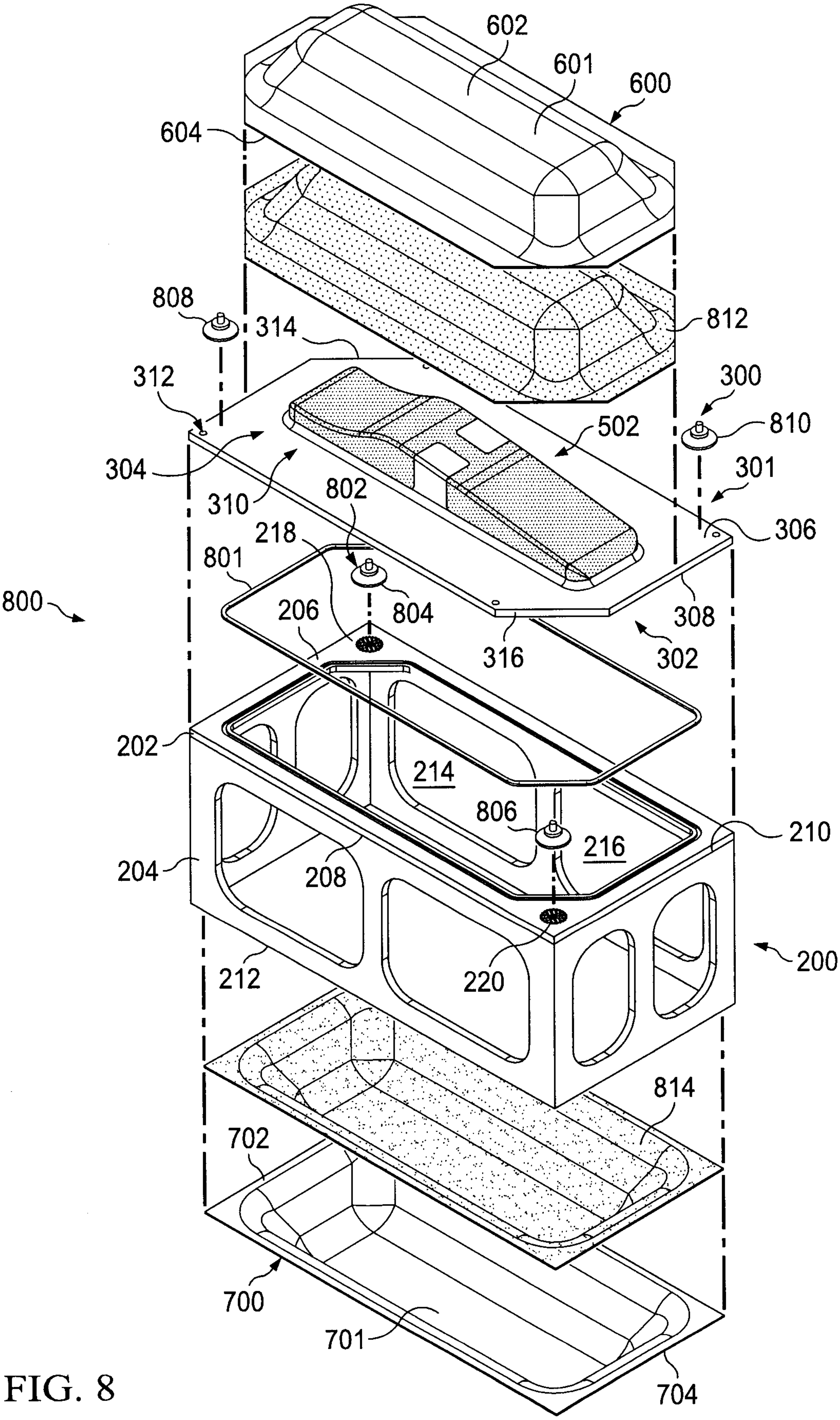


FIG. 7


602
601
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814
702
700
701
704

FIG. 8

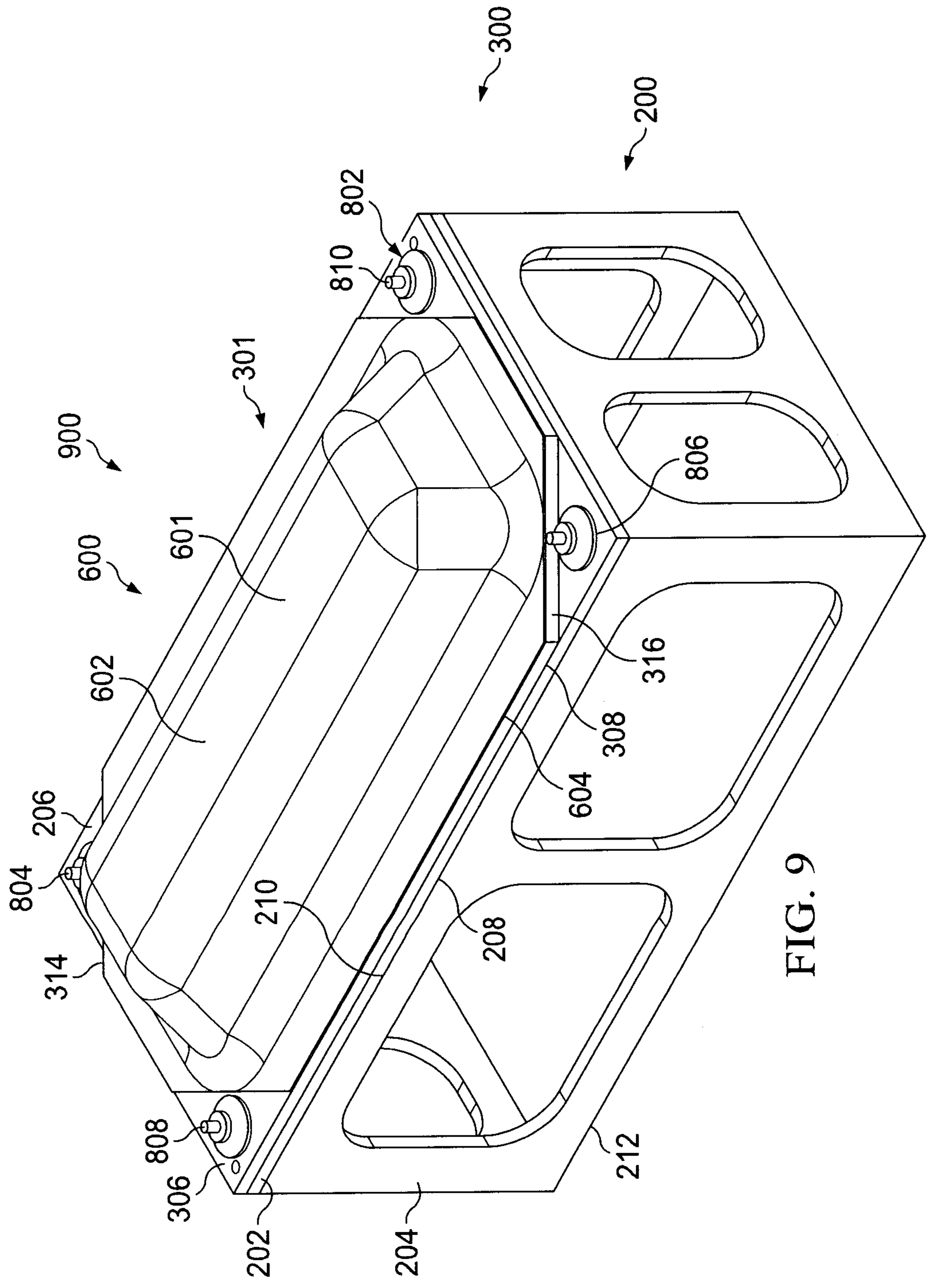

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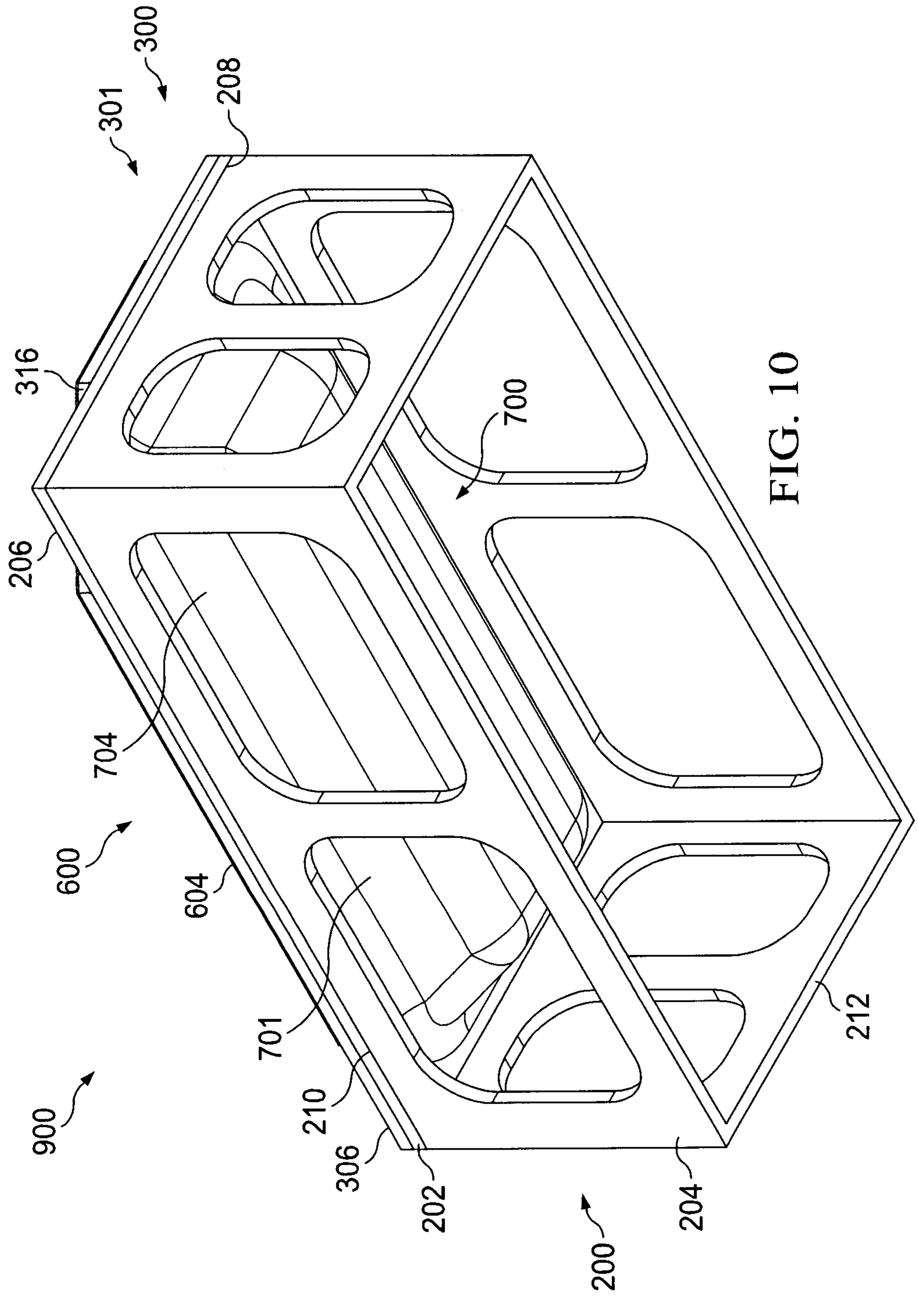
FIG. 9


300
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316
206
704
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604
701
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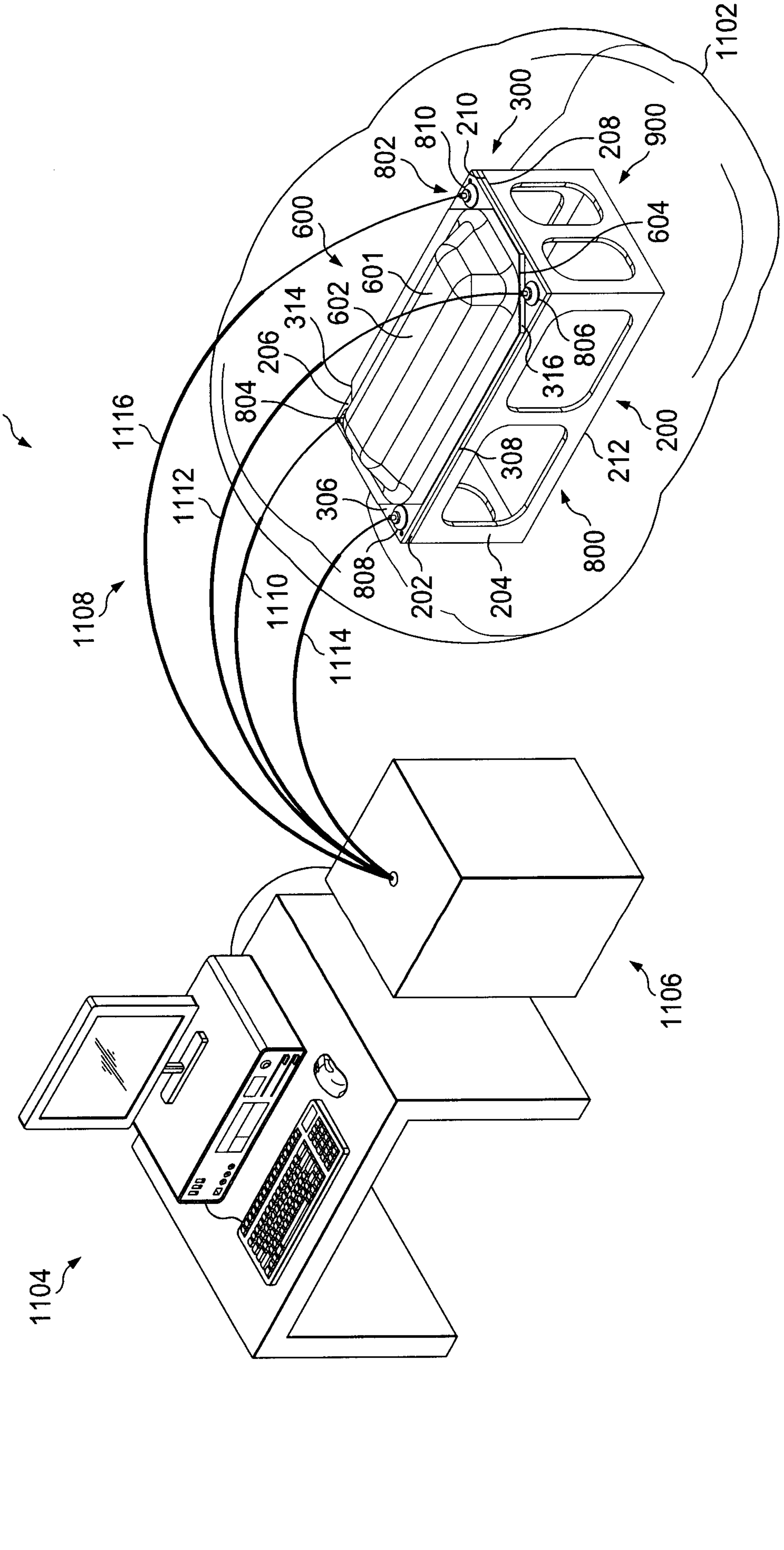
306
900
202
200
204
212
700

FIG. 10


1100
1102
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802
208
900
600
604
601
602
314
206
804
806
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1116
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204
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1108
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1114
1106
1104

FIG. 11

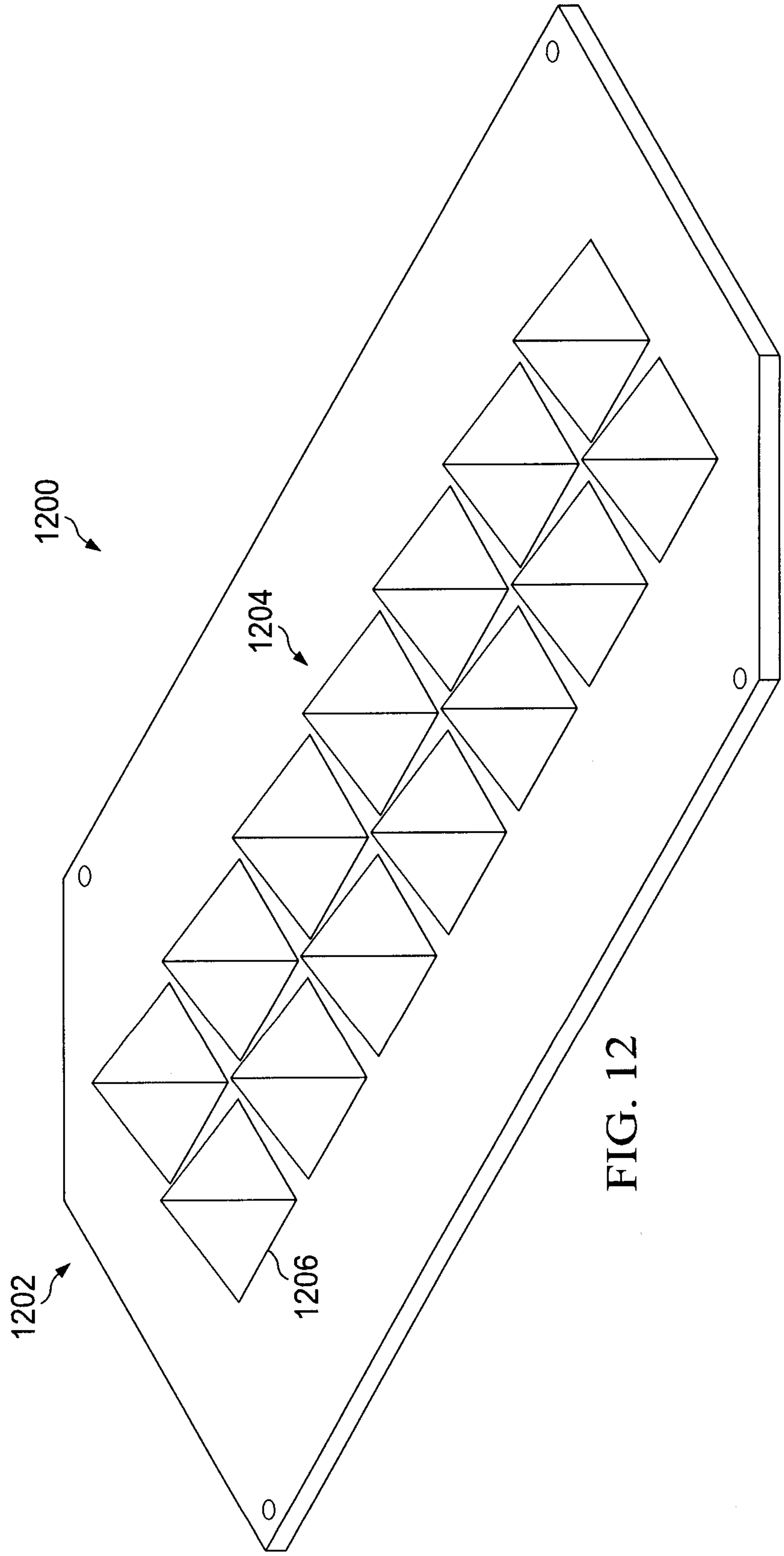
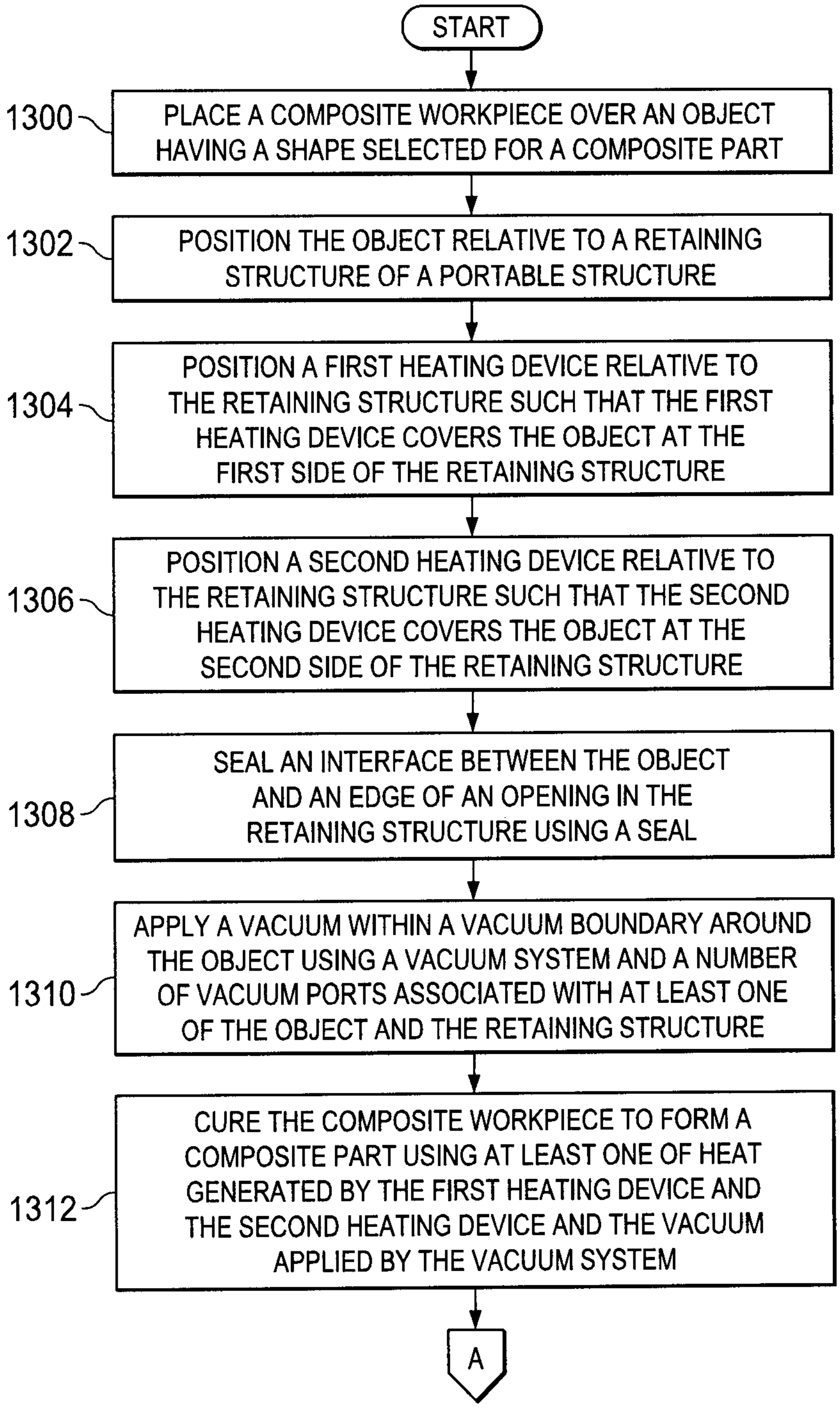


FIG. 12

FIG. 13A



TO FIG. 13B

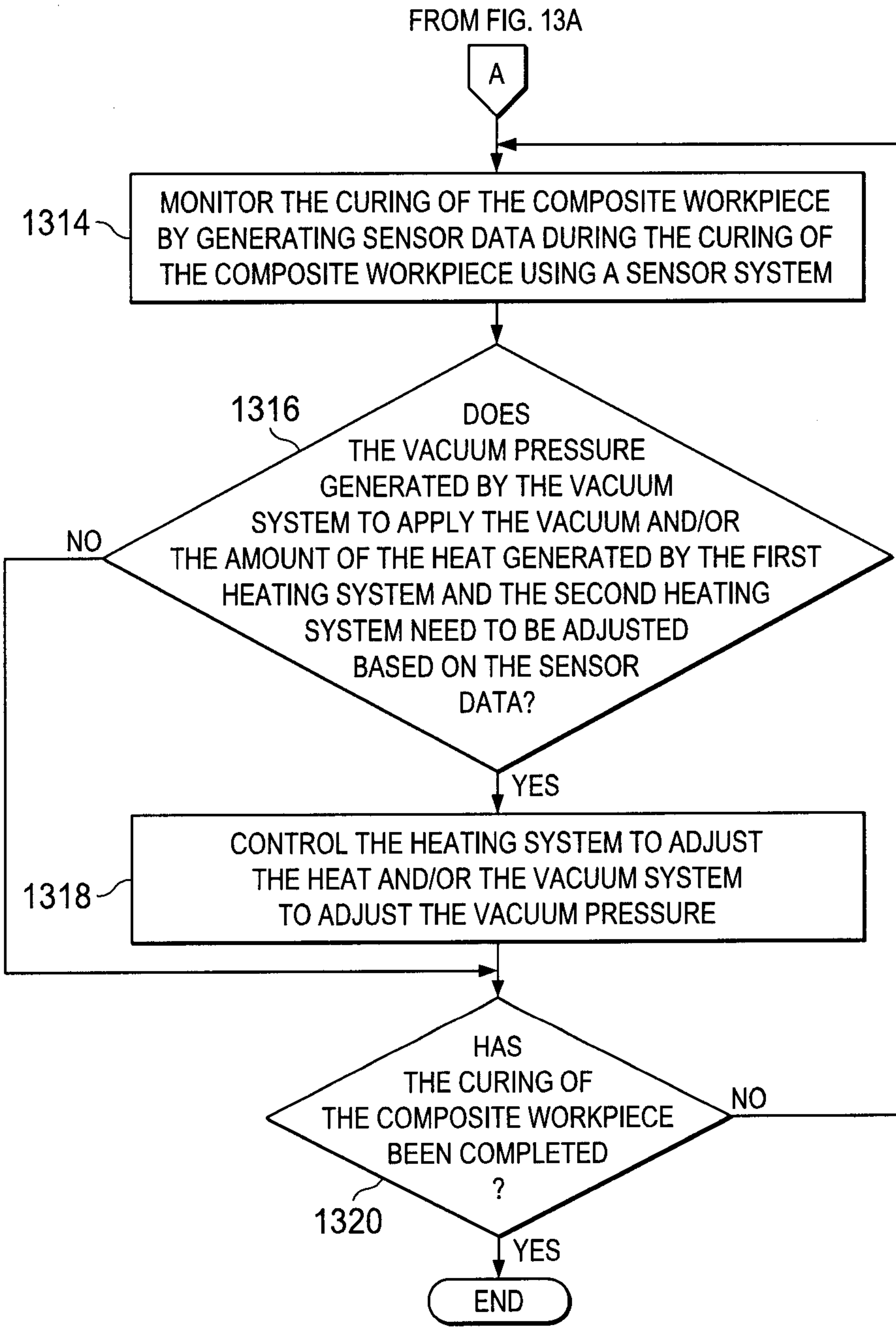

FROM FIG. 13A
A
1314
MONITOR THE CURING OF THE COMPOSITE WORKPIECE BY GENERATING SENSOR DATA DURING THE CURING OF THE COMPOSITE WORKPIECE USING A SENSOR SYSTEM
1316
DOES THE VACUUM PRESSURE GENERATED BY THE VACUUM SYSTEM TO APPLY THE VACUUM AND/OR THE AMOUNT OF THE HEAT GENERATED BY THE FIRST HEATING SYSTEM AND THE SECOND HEATING SYSTEM NEED TO BE ADJUSTED BASED ON THE SENSOR DATA?
NO
YES
1318
CONTROL THE HEATING SYSTEM TO ADJUST THE HEAT AND/OR THE VACUUM SYSTEM TO ADJUST THE VACUUM PRESSURE
HAS THE CURING OF THE COMPOSITE WORKPIECE BEEN COMPLETED ?
NO
1320
YES
END

FIG. 13B

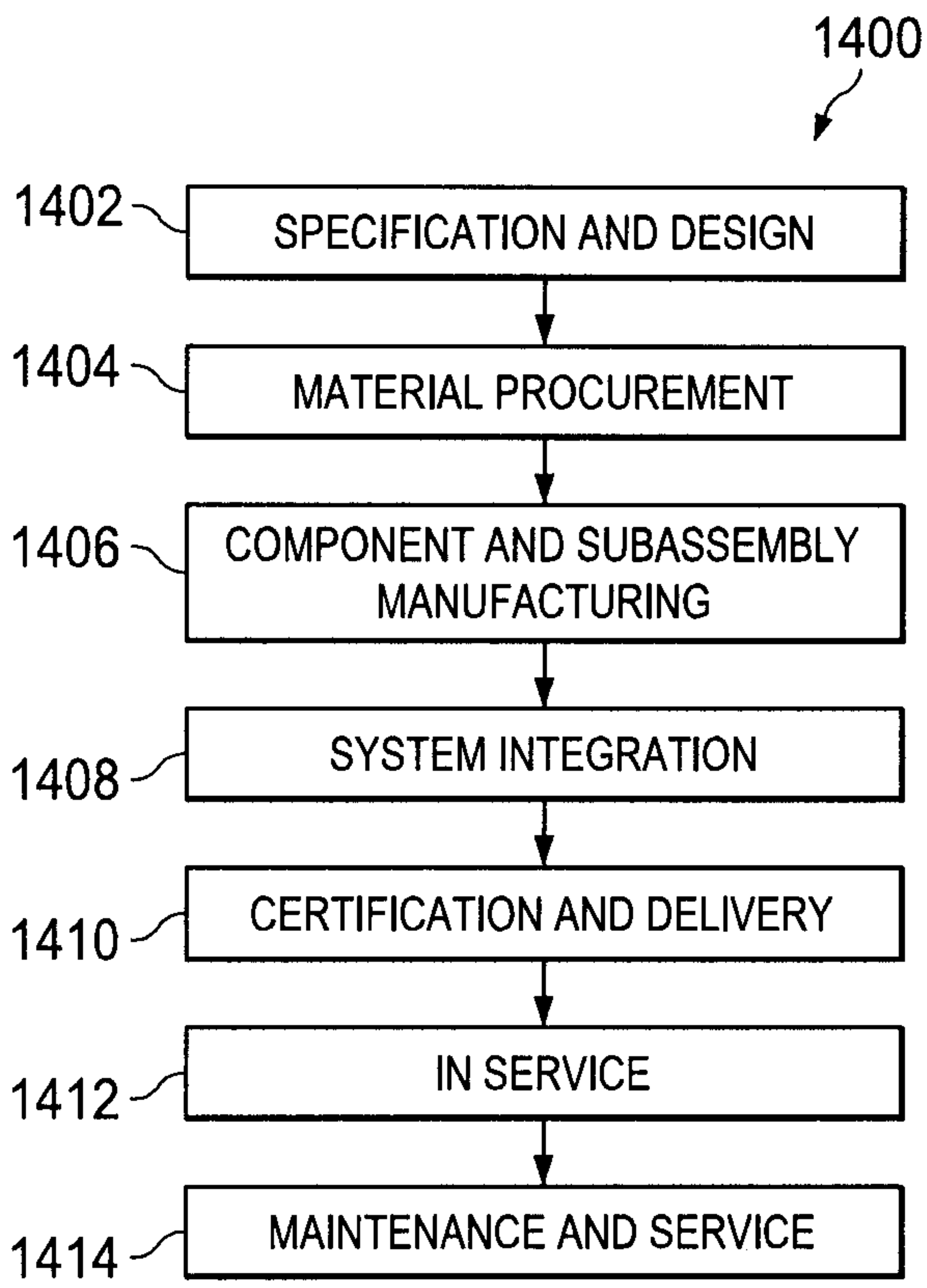
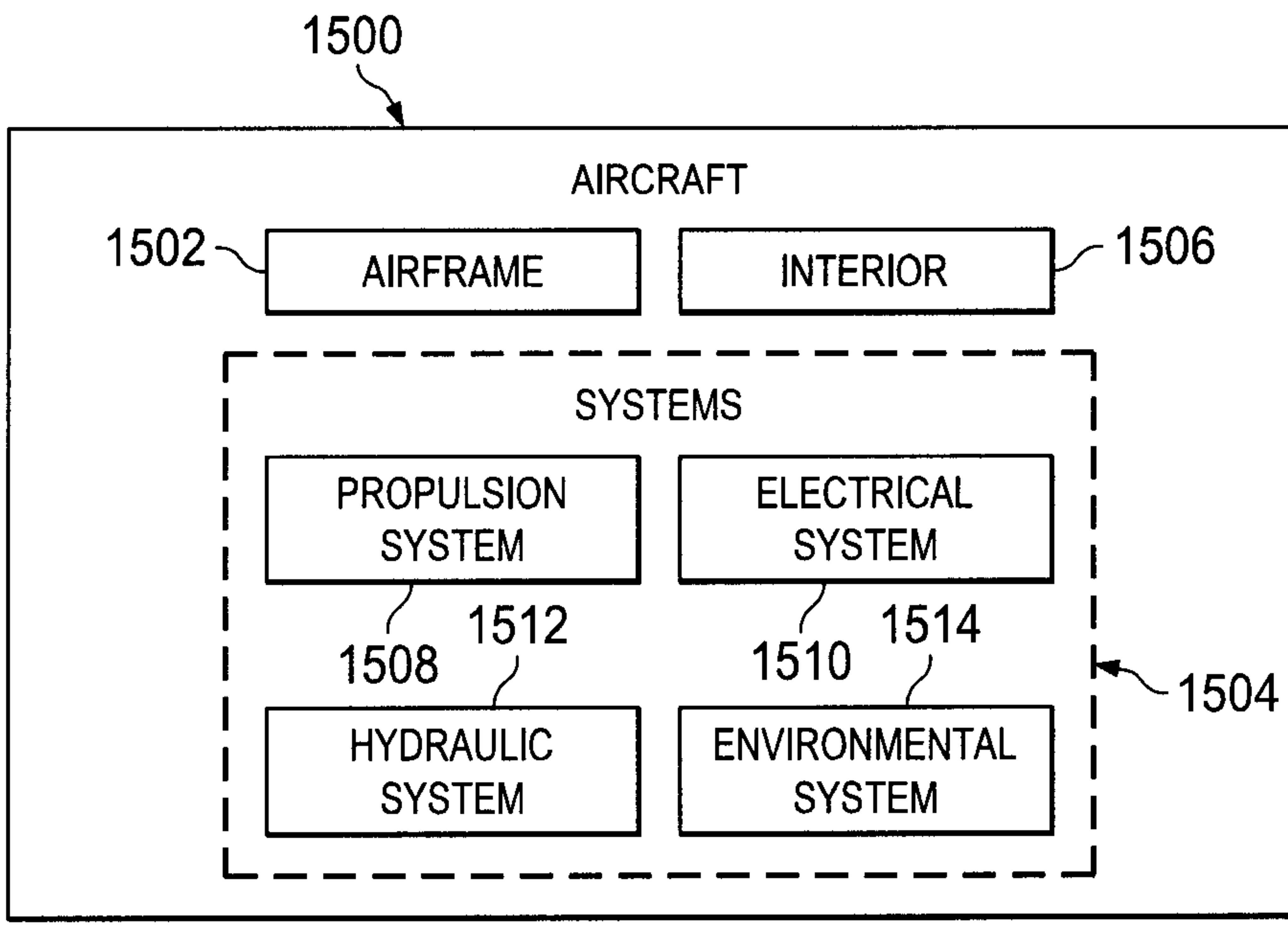

1400
1402
SPECIFICATION AND DESIGN
1404
MATERIAL PROCUREMENT
1406
COMPONENT AND SUBASSEMBLY MANUFACTURING
1408
SYSTEM INTEGRATION
1410
CERTIFICATION AND DELIVERY
1412
IN SERVICE
1414
MAINTENANCE AND SERVICE

FIG. 14


1500
AIRCRAFT
1502
AIRFRAME
INTERIOR
1506
SYSTEMS
PROPULSION SYSTEM
ELECTRICAL SYSTEM
1508
1512
1510
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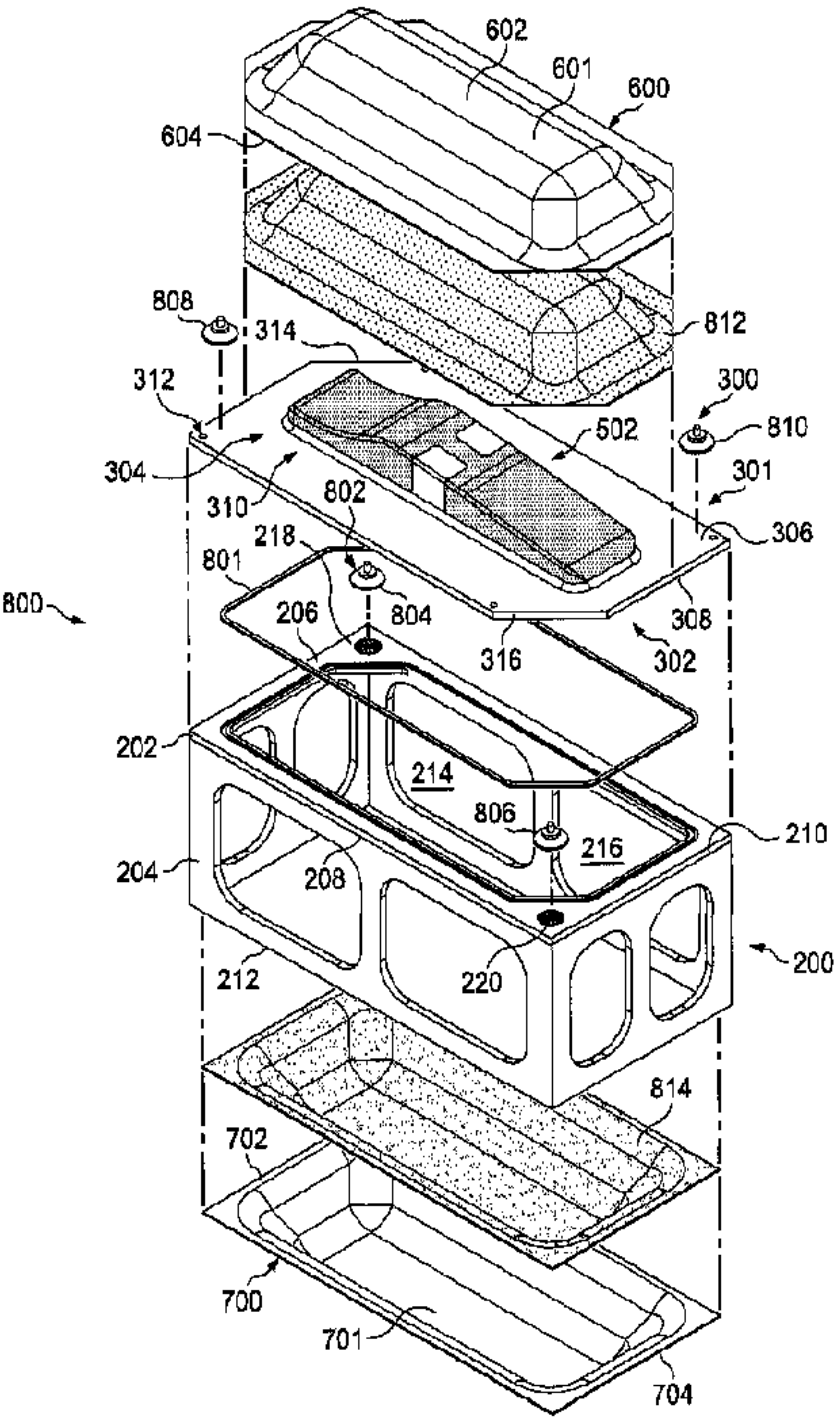
HYDRAULIC SYSTEM
ENVIRONMENTAL SYSTEM

FIG. 15



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704