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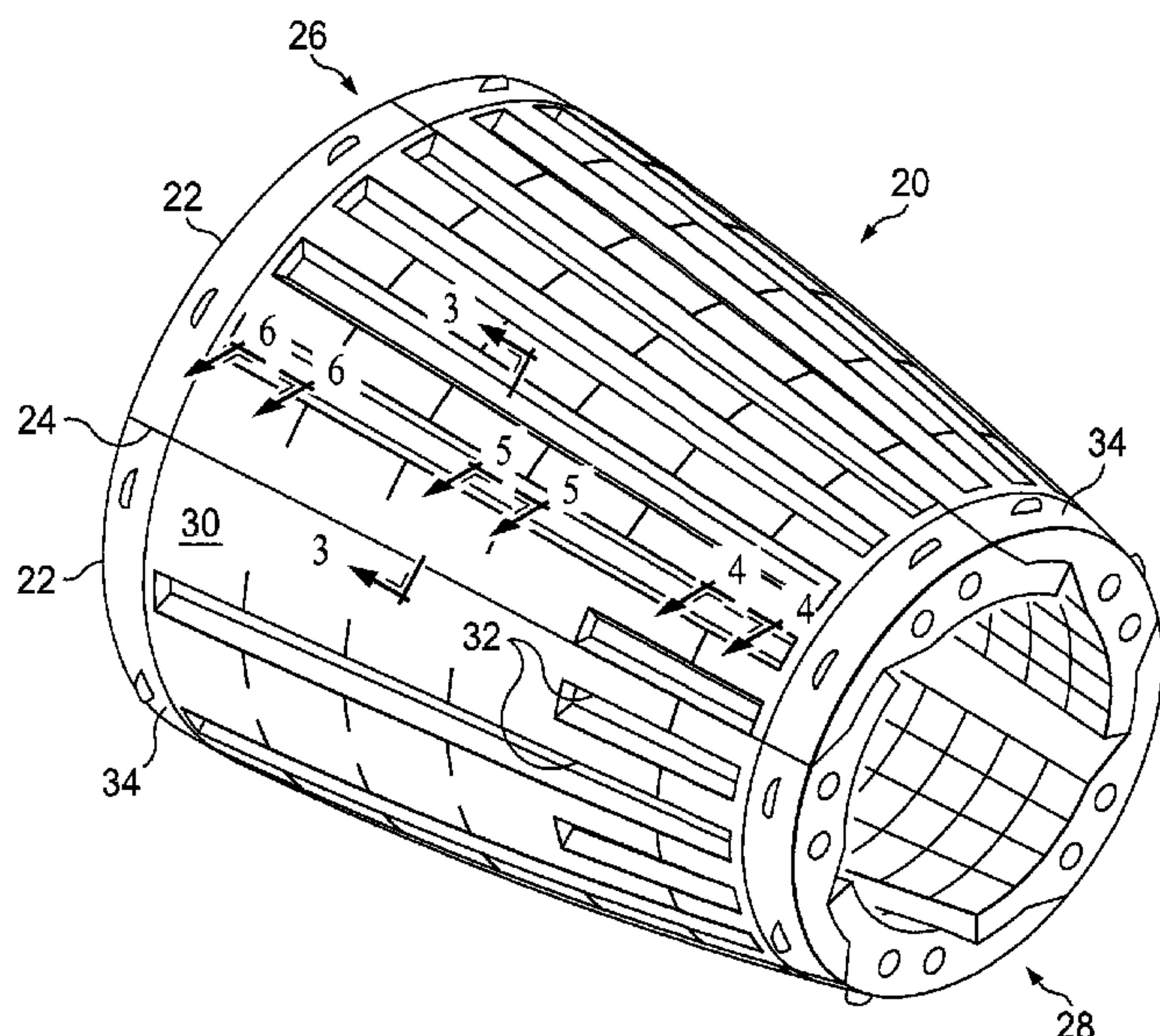
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A substantially air-tight triple seal arrangement along a seam between first and second tool segments comprises inner, middle and outer seals forming first and second substantially air tight vacuum chambers.

ABSTRACT

A substantially air-tight triple seal arrangement along a seam between first and second tool segments comprises inner, middle and outer seals forming first and second
5 substantially air tight vacuum chambers.

SEALING AND TESTING SEGMENTED TOOLS

BACKGROUND INFORMATION

5 1. **Field:**

The present disclosure generally relates to segmented tools having multiple pieces that are sealed together, and deals more particularly with a triple seal arrangement and related method allowing the integrity of the individual seals to be tested and monitored.

10 2. **Background:**

Some tools comprise multiple pieces or segments that must be assembled, but which are required to function and perform function as a seamless, single tool. For example, in the aircraft industry, a large composite fuselage section may be laid up on, vacuum bagged and then autoclave cured on a generally cylindrical mandrel comprising 15 multiple circumferential mandrel segments. The mandrel segments are assembled along seams. Following curing and de-bagging, the mandrel segments must be disassembled in order to allow release and removal of the cured fuselage section from the tool.

Each seam between the mandrel segments may be sealed with a substantially air-tight seal extending along joining surfaces of adjacent mandrel segments. Air leakage 20 through any of one of these seals may reduce compaction pressure applied to the fuselage section during curing. A reduction in compaction pressure during curing due to an air leak may have an undesirable effect on the quality and/or performance of the cured fuselage section.

One proposed solution to the problem of seal leakage involves the provision of 25 double seals along the seams between the mandrel segment seams. The double seals are arranged to form a chamber that may be used to perform a pass or fail leak test, however, the test does not indicate which of the double seals may have lost its integrity. If the test fails, indicating that the integrity of at least one of the seals may have been compromised, the tool segments must be disassembled, and the seals must be repaired or replaced, 30 following which the mandrel segments must be reassembled and the leak test must be repeated. The process of disassembling/reassembling and replacing the seals is time consuming, labor intensive and may reduce production throughput and build rate.

Accordingly, there is a need for a method of sealing and testing the integrity of seals in segmented tools such as mandrels that allows continuous monitoring of seal integrity. There is also a need for a seal arrangement and testing method which will identify which, if any, of the seals are leaking and whether at least one seal has retained its integrity.

5

SUMMARY

The disclosed embodiments provide a method and system for sealing and testing multi-piece tools such as segmented mandrels, in an autoclave environment. A triple seal along seams between the mandrel segments provide added protection against loss vacuum pressure due to seal leaks. The triple seal may be tested for leaks during assembly of the mandrels, before a layup is placed on the tool and loaded into an autoclave. The need for replacing and/repairing seals is reduced, the quality of cured parts may be improved, and production throughput may be increased.

According to one disclosed embodiment, a method is provided for sealing and monitoring multiple segments of a mandrel in an autoclave environment. The method involves forming an inner bag vacuum chamber overlapping ends and seams of the mandrel segments and an inner seal between the mandrel segments, and forming an outer vacuum bag chamber and an H-shaped seal area on opposite ends of the inner bag vacuum chamber. The method also involves forming an outer seal chamber using the H-shaped seal area, the inner seal and a middle seal, forming an inner seal chamber using the middle seal and the inner seal, and monitoring the integrity of any of the inner seal, the middle seal and the outer seal.

The method may further involve pressing the inner seal, the middle seal, the outer seal and legs of the H-shaped seal area into grooves within the mandrel segments. Forming the outer vacuum bag chamber may involve sealing the legs of the H-shaped seal area to the inner and outer vacuum bags. Forming the outer bag vacuum chamber may involve sealing legs of the H-shaped seal area to the inner seal and the middle seal. Monitoring the integrity may involve sensing a change in vacuum pressure within any of the inner bag vacuum chamber, the inner seal chamber and the outer seal chamber.

According to another embodiment, a substantially air-tight seal arrangement along a seam between first and second tool segments is provided. The substantially air-tight seal arrangement includes middle and outer seals forming first and second substantially air tight vacuum chambers, and an H-shaped seal area located at opposite ends of the seam and 5 connected to the middle seal and the outer seal.

The inner, middle and outer seals may extend along a length of the seam, and may be arranged in an H-shaped pattern at each of opposite ends of the seam. The first and second tool segments may be arranged to form a layup surface, and the H-shaped pattern may include first and second legs adapted to be sealed to first and second vacuum bags covering 10 the layup surface. The inner, the middle and the outer seals may be spaced apart from, and may extend longitudinally along the seam. The inner and middle seals may be spaced apart from each other and form the first vacuum chamber, and the middle and outer seals may be spaced apart from each other and form the second vacuum chamber. Each of the first and 15 second vacuum chambers may be adapted to be coupled with a vacuum source and a vent for independently testing the inner, middle and outer seals for air leaks. The seal arrangement may also comprise first and second vacuum probes for respectively sensing vacuum pressure in the first and second vacuum chambers.

According to another embodiment there is provided a method for sealing and monitoring multiple segments of a mandrel in an autoclave environment. The method 20 involves forming an inner bag vacuum chamber overlapping ends and seams of the mandrel segments and an inner seal between the mandrel segments; forming an outer vacuum bag chamber and an H-shaped seal area on opposite ends of the inner bag vacuum chamber; forming an outer seal chamber using the H-shaped seal area, the inner seal and a middle seal; forming an inner seal chamber using the middle seal and the inner seal; and monitoring the 25 integrity of any of the inner seal, the middle seal and the outer seal.

The method may further involve pressing the inner seal, the middle seal, the outer seal and legs of the H-shaped seal area into grooves within the mandrel segments.

Forming the outer vacuum bag chamber may involve sealing the legs of the H-shaped seal area to the inner and outer vacuum bags.

Forming the outer bag vacuum chamber may involve sealing legs of the H-shaped seal area to the inner seal and the middle seal.

5 Monitoring the integrity may involve sensing a change in vacuum pressure within any of the inner bag vacuum chamber, the inner seal chamber and the outer seal chamber.

According to another embodiment there is provided a method of sealing and testing the integrity of seals between at least two segments of a tool, including arranging an inner seal, an outer seal and a middle seal to form first and second seal chambers between the two 10 tool segments; applying a vacuum to each of the first and second seal chambers; and detecting a leak in the inner seal or the outer seal by sensing a change in vacuum pressure within the first and second seal chambers.

The method may further involve placing an H-shaped seal area between the two tool segments, and connecting legs of the H-shaped seal area to each of the middle and the outer 15 seals.

The method may further involve placing an inner vacuum bag over the two tool segments, and sealing the inner vacuum bag to the H-shaped seal area.

The method may further involve placing an outer vacuum bag over the two tool segments covering the inner vacuum bag, and sealing the outer vacuum bag to legs of the H- 20 shaped seal area.

The method may further involve using the outer vacuum bag to apply pressure to a seal between the inner vacuum bag and the H-shaped seal area.

According to yet another embodiment there is provided a method of autoclave processing a composite part on a segmented tool. The method involves forming a triple seal 25 between adjoining segments of the tool, including forming an inner seal, a middle seal and an outer seal; placing an inner vacuum bag over the segmented tool covering the composite part; forming an inner bag vacuum chamber by forming a seal between the inner vacuum bag and the inner seal; placing an outer vacuum bag over the segmented tool covering the inner

vacuum bag; forming an outer bag vacuum chamber by forming a seal between the outer vacuum bag and the outer seal; drawing vacuums respectively within the inner vacuum bag chamber and the outer vacuum bag chamber; using the outer vacuum bag to apply pressure to the seal between the inner vacuum bag and the inner seal; and compressing the triple seal by 5 applying autoclave pressure to the segments of the tool.

The method may further involve detecting a leak in any one of the inner seal, the middle seal or the outer seal.

The inner seal, the middle seal and the outer seal may be arranged to form an inner seal chamber and an outer seal chamber, and the method may further involve detecting the 10 leak is performed by sensing a change in vacuum pressure in either the inner seal chamber or the outer seal chamber.

Forming the outer vacuum bag chamber may further involve forming an H-shaped seal between the adjoining segments of the tool outside of the inner vacuum bag chamber.

According to still another embodiment there is provided a substantially air-tight seal 15 arrangement along a seam between first and second tool segments. The seal arrangement includes inner, middle and outer seals forming first and second substantially air tight vacuum chambers; and an H-shaped seal area located at opposite ends of the seam and connected to the middle seal and the outer seal.

The inner, middle and outer seals may extend along a length of the seam, and may be 20 arranged in an H-shaped pattern at each of opposite ends of the seam.

The first and second tool segments may be arranged to form a layup surface, and the H-shaped pattern may include first and second legs adapted to be sealed to first and second vacuum bags covering the layup surface.

The inner, the middle and the outer seals may be spaced apart from, and may extend 25 longitudinally along the seam.

The inner and middle seals may be spaced apart from each other and form the first vacuum chamber, and the middle and outer seals may be spaced apart from each other and form the second vacuum chamber.

5 Each of the first and second vacuum chambers may be adapted to be coupled with a vacuum source and a vent for independently testing the inner, middle and outer seals for air leaks.

The seal arrangement may further include first and second vacuum probes for respectively sensing vacuum pressure in the first and second vacuum chambers.

10 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

15 The novel features believed characteristic of the illustrative embodiments are set forth in the appended claims. The illustrative embodiments 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 illustration of a perspective view of a segmented mandrel having seams with triple seals according to the disclosed method.

20 Figure 2 is an illustration of a cross-sectional view of a composite shell laid up and cured on the segmented mandrel shown in Figure 1.

Figure 3 is an illustration of a sectional view taken along the line 3-3 in Figure 1.

Figure 4 is illustration of a perspective view of the forward end of the triple seal between mandrel segments at the location along the seam designated as "4" in Figure 1.

Figure 5 is illustration of a perspective view of a middle section of the triple seals between the mandrel segments at the location along the seam designated as "5" in Figure 1.

5 Figure 6 is illustration of a perspective view of an aft end of the triple seals between the mandrel segments at the location along the seam designated as "6" in Figure 1.

Figure 7 is an illustration of a cross-sectional view of another embodiment of a seam between two of the mandrel segments.

10 Figure 8 is an illustration of a cross-sectional view of a further embodiment of a seam between two of the mandrel segments.

Figure 9 is illustration of a diagrammatic cross-sectional view along one of the seams, showing how the triple seal is connected to the inner and outer vacuum bags.

Figure 10 is an illustration similar to Figure 9, but showing a temporary plate having been installed for testing the triple seal during assembly of the mandrel segments.

5 Figure 11 is an illustration of a functional block diagram showing the components of the segmented mandrel and a related control system for testing and monitoring the triple seal.

Figure 12 is an illustration of a flow diagram of a method of sealing a segmented tool.

10 Figure 13 is an illustration of a flow diagram of an alternate embodiment of a method of sealing a segmented tool.

Figure 14 is an illustration of a flow diagram of aircraft production and service methodology.

Figure 15 is an illustration of a block diagram of an aircraft.

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DETAILED DESCRIPTION

Referring to Figures 1 and 2, a segmented layup tool **20** (Figure 1), sometimes also hereinafter referred to as a segmented mandrel **20**, may be used as a mandrel on which a composite part may be laid up and cured. For example, and without limitation, 20 the segmented mandrel **20** may be used to layup and a cure the composite shell **36** shown in Figure 2. The composite shell **36** includes an outer composite skin **38** stiffened by longitudinally extending, composite stringers **40**. Although not shown in Figure 2, the composite shell **36** may be attached to a circumferentially extending, internal frame to form a barrel section of an airplane fuselage (not shown).

25 The layup tool **20** includes a forward end **26** and an aft end **28**, and comprises a plurality of mandrel segments **22** that are joined together along longitudinal seams **24**. As will be discussed below in more detail, the seams **24** include a triple, substantially air-tight seal (not shown in Figure 1) that seals the mandrel segments together **22** so that they act as a single tool. In the illustrated embodiment, the layup tool **20** has a generally 30 tapered cylindrical or barrel shape, however other shapes are possible, depending upon the shape of the part to be fabricated.

The mandrel segments 22 collectively form a layup surface 30 upon which composite material such as pre-preg, may be laid up to form the composite shell 36 shown in Figure 2. The layup surface 30 forms the IML (inner mold line) of the composite skin 38, and may include a plurality of circumferentially spaced, longitudinally extending stringers grooves 32 into which preformed composite stringer layups (not shown in Figure 1) may be placed before the skin 38 is laid up over the layup surface 30. The layup tool 20 further includes a substantially smooth, circumferentially extending bands 34 on the forward and aft ends 26, 28 which are located longitudinally beyond the layup surface 30. The bands 34 provide a surface to which one or more later discussed 10 vacuum bags (not shown in Figures 1 or 2) may be attached and sealed in order to compact and consolidate the composite shell 36 during curing, which may be carried out within an autoclave (not shown).

Figures 3-6 illustrate one embodiment of a lap joint or seam 24 between two adjacent ones the mandrel segments 22a, 22b. Figure 3 depicts a composite skin 56 having been laid up on layup surface 30, covered by a caul plate 58, an inner vacuum bag 60 and an outer vacuum bag 94. For simplicity of description, additional elements such as release films, breathers, etc. are not shown. As will be discussed later in more detail, the inner vacuum bag 60 is sealed to the bands 34 (Figure 1), outside of the layup surface 30. In one embodiment, the seams 24 between the mandrel segments 22a, 22b are formed by 20 overlapping, peripheral inner and outer flanges 68, 70 forming mating, sealing surfaces 42. The sealing surfaces 42 are sealed together by a substantially air-tight triple seal 44 comprising an outer first seal 46, a middle second seal 48, and an inner third seal 50. The opposite ends of the seals 46, 48, 50 are arranged and connected to form H-shaped seal 25 areas 82 which are respectively located beyond the ends of the skin layup 56, beneath the bands 34.

Referring to Figures 4 and 6, each of the H-shaped seal areas 82 comprises a pair of inner legs 83, 84, a pair of outer legs 85, 86 and a cross leg 87. In the illustrated embodiment, the legs 83, 84, 85, 86 and 87 are arranged in the shape of an "H", however, depending upon the application, these legs may be arranged to form other shapes. The 30 outer ends or tips 85a, 86a of the outer legs 85, 86 are respectively sealed to the inner and outer vacuum bags 60, 94 (see Figure 9). The seals 46, 48, 50 may be formed, for example and without limitation, by casting and/or extruding a suitable material such as

silicone. The outer, middle and the inner seals **46**, **48**, **50** respectively, are circumferentially spaced apart from each other, and in the illustrated embodiment, are held within respectively associated grooves **52** (Figure 3) formed in the sealing face **42** of the outer flange **70**. The tips **85a**, **86a** may be formed of a material such as, without limitation, Viton® or a similar fluoroelastomer which is suited to provide good adherence to vacuum bag sealant (not shown) used to seal the tips **85a**, **85b** to the inner and outer vacuum bags **60**, **94**. In other embodiments, the outer, middle and the inner seals **46**, **48**, **50** respectively, as well as the H-shaped seal areas **82** may be held in grooves (not shown) formed in the inner flange **68**, and seal against the outer flange **70**. In still other embodiments some of the seals **46**, **48**, **50** and the seal area **82** may be formed in each of the inner and outer flanges **68**, **70** respectively.

The area between the middle seal **48** and the inner seal **50** forms an inner, first seal chamber **64**, and the area between the middle seal **48** and the outer seal **46** forms an outer, second seal chamber **66**. The inner flange **68** is provided with at least one vacuum port **72** and a pressure probe **76** which communicate with the outer seal chamber **66**. The inner flange **68** is also provided with at least one vacuum port **74** and a pressure probe **78** which communicate with the inner seal chamber **64**. The vacuum port **72** is used to selectively draw a vacuum or vent the outer seal chamber **66**, and a change in the pressure within the outer seal chamber **66** may be sensed by pressure probe **76**. Similarly, the vacuum port **74** is used to selectively draw a vacuum or vent the inner seal chamber **64**, and a change in the pressure within the inner seal chamber **64** may be sensed by the vacuum pressure probe **78**. Although not shown in Figure 3, one or more vacuum ports and pressure probes are coupled with the area beneath each of the inner and outer vacuum bags **60**, **94** in order to evacuate the vacuum bag **60**, **94** and separately sense vacuum pressures within the inner and outer vacuum bags **60**, **94**. The inner bag **60** forms an inner bag vacuum chamber **92** (Figure 9) within which a part vacuum **71** is drawn. The compaction pressure applied by the inner bag **60** to the composite skin layup **56** is supplemented by pressure applied by the outer bag **94**, and external autoclave pressure **62**.

Figure 7 illustrates an alternate embodiment of one of the seams **24** employing a triple seal **44**, similar to the embodiment shown in Figure 3. In this example, the seams **24** between adjacent mandrel segments **22a**, **22b** are formed adjacent to the centerline **54** of

the stringer grooves **32** into which stringer layups (not shown) are placed before the composite skin **38** is laid up over the layup tool **20**. In this example, part of each stringer groove **32** is formed along each of the mandrel segments **22a**, **22b** at the seam **24**.

Figure 8 illustrates a further embodiment of a seam **24** between adjacent mandrel segments **22a**, **22b**. In this example, the mandrel segments **22a**, **22b** respectively have opposing flanges **88**, **90** which extend radially inwardly from the layup surface **30**, effectively forming a sealed joint between the mandrel segments **22a**, **22b** along the seam **24**.

Attention is now directed to Figure 9 which diagrammatically illustrates components of the layup tool **20** along one of the seams **24**; a caul plate, breathers, and release films having been omitted for simplicity. The composite skin **56** is laid up on the layup surface **30** which forms the IML of the finished part. The inner vacuum bag **60** is sealed by an inner bag seal **100** to the layup tool **20** around the band **34**, and to the tips **85a** of the outer legs **86** of the H-shaped seal area **82**. In embodiments utilizing a caul plate (not shown), the inner vacuum bag **60** may be sealed to the caul plate or to a caul plate vacuum bag (not shown).

The outer vacuum bag **94** is sealed by an outer bag seal **98** to the bands **34**, outside of the inner bag seal **100**, and to the tips **86a** of the outer legs **85** of the H-shaped seal area **82**. The outer seal legs **85**, **86** along with seal legs **87** form an outer bag vacuum chamber **96** which communicates with the area **93** beneath the outer vacuum bag **94**. The inner vacuum bag **60** is in communication with an inner vacuum bag chamber **92** formed by the inner seal **50** and the outer legs **86** of the H-shaped seal area **82**. The inner seal chamber **64** is defined by the middle seal **48**, the inner seal **50** and the inner legs **83**, **84** of the H-shaped seal area **82**. The outer seal chamber **66** is defined by the outer seal **46**, the middle seal **48** and the inner legs **83**, **84** of the H-shaped seal area **82**. During processing of the composite skin layup **56** in an autoclave, evacuation of the outer vacuum bag **94** draws the outer vacuum bag **94** down against and compresses the inner bag seal **100**. The compressive force applied to the inner bag seal **100** by the outer vacuum bag **94** supplements the applied autoclave pressure **62**, to reduce the possibility of air leaks through the inner bag seal **100**.

The area **80** beneath the inner vacuum bag **60** along with the inner bag vacuum chamber **92** are coupled with a vacuum ports **104**. One or more vacuum pressure probes

106 are provided to sense a change in vacuum pressure within the inner vacuum bag 60 and the inner bag vacuum chamber 92. Similarly, one or more vacuum ports 74 are coupled with the inner seal chamber 64 to selectively draw a vacuum or vent the inner seal chamber 64. One or more vacuum pressure probes 78 are used to sense a change in 5 vacuum pressure within the inner seal chamber 64. Also, one or more vacuum ports 72 are coupled with the outer seal chamber 66 to selectively draw a vacuum or vent the outer seal chamber 66. One or more pressure probes 76 are used to sense a change in vacuum pressure within the outer seal chamber 66. Additional vacuum ports 102 are used to selectively draw a vacuum in, or vent the outer bag vacuum chambers 96.

10 Referring now to Figure 10, correct assembly of the mandrel segments 22 shown in Figure 1, and the integrity of triple seal 44 as well as the H-shaped seal area 82 may be tested as the mandrel segments 22 are being assembled, prior to placing a composite layup on the layup tool 20 for processing. By testing the triple seal 44 during the mandrel assembly phase, seal leaks may be detected and corrected before the tool 20 and 15 composite layup is loaded into an autoclave. In order to test the triple seal 44, a temporary test plate 105 is placed over each seam 24 between the mandrel segments 22, and is sealed to the tips 85a, 86a of the H-shaped seal area 82 by outer seal 98 and inner seal 100. The test plate closes off the inner bag vacuum chamber 92 and the outer bag vacuum chamber 96. Vacuums are drawn in the inner seal chamber 64, the outer seal chamber 66, 20 the inner bag vacuum chamber 92, and the outer bag vacuum chamber 96. A leak in the outer seal 46, the middle seal 48 or inner seal 50 results in a change in vacuum pressure within the inner seal chamber 64, the outer seal chamber 66 and/or the inner bag vacuum chamber 92, and these changes in the vacuum pressure are detected by the respectively associated vacuum probes 78, 76 at 106.

25 Similarly, the integrity of the H-shaped seal area 82 may be checked for leaks. In the event that the outer legs 85 have a leak, the resulting change in the vacuum pressure in the outer bag vacuum chamber 96 will be detected by the vacuum probes 107. In the event that both of the outer legs 85, 87 have a leak, the vacuum pressure within the inner bag chamber 92 is reduced, and this reduction in vacuum pressure is sensed by vacuum 30 probes 106.

Figure 11 broadly illustrates the components of a system for testing and monitoring the integrity of seals used to seal a multi-piece, segmented tool such as a

segmented layup mandrel **20**. A composite layup **56** may be laid up on the segmented mandrel **20**, and covered by one or more vacuum bags **60, 94**. The vacuum bags **60, 94** are individually sealed to the segmented mandrel **20**. The segments **22** of the mandrel **20** are sealed to each other along seams **24** by a triple seal **44**. The airtight chambers **64, 66, 92** formed by the triple seal **44** are coupled with vacuum pressure probes **76, 78, 106** and vacuum ports **72, 74, 102, 104**, as previously described. A controller **108**, which may comprise a programmed general purpose computer or a PLC (programmable logic controller) receives pressure data from the vacuum pressure probes **76, 78, 106** and selectively connects the vacuum ports **72, 74, 102, 104** with a vacuum source **110** or a vent **115**.

Referring now again to Figure 9, after the mandrel segments **22** have been assembled, and a composite skin **56** has been laid up on the layup surface **30** of the mandrel **20**, the mandrel **20** is placed in an autoclave (not shown) where autoclave pressure **62** and heat are applied. Vacuum ports **72, 74, 102, 104** are used to draw 15 vacuums the inner seal chamber **64**, the outer seal chamber **66**, the inner vacuum bag chamber **92** and the outer bag vacuum chamber **96**. The vacuum generated within the inner bag vacuum chamber **92**, along with autoclave pressure **62** compact and consolidate the composite layup **56** during a cure cycle. The outer vacuum bag **94** may add additional compaction pressure to the composite skin layup **56**, and also applies a compressive force 20 to the inner bag seal **100**.

If the triple seal **44** is functioning properly (without air leaks), vacuum pressure probes **76, 78** and **106** register relatively low, preselected levels of vacuum pressure indicating that the integrity of the outer seal **46**, the middle seal **48** and the inner seal **50** is intact. In the event of a leak in the outer seal **46**, air pressure enters the outer seal chamber **66**, causing a change (reduction) in the vacuum pressure within the outer seal chamber **66**. This change in vacuum pressure is detected by the vacuum probe **76**. In the event of a leak in the outer seal **46**, the middle seal **48** and the inner seal **50** maintain the required vacuum pressure in the inner bag vacuum chamber **92**.

In the event that both of the outer seal **46** and the middle seal **48** have leaks, air 30 pressure enters the inner seal chamber **64** but the inner seal **50** maintains the required vacuum pressure in the inner bag chamber **92**. Under these circumstances, the leak in the middle seal **48** allows air pressure to enter the inner seal chamber **64**. A reduction in the

vacuum pressure within the inner seal chamber **64** is detected by the vacuum pressure probe **78**. In the event of leaks in each of the outer seal **46**, middle seal **48** and inner seal **50**, air pressure enters the inner vacuum bag chamber **92** and the resulting change in vacuum pressure is detected by the vacuum probes **106**.

5 It may be possible to detect a leak in the middle seal **48** under circumstances where there is no leak in the outer seal **46**. This middle seal **48** leak detection may be achieved by maintaining the vacuum pressure in the inner seal chamber **64** at a level that is greater than the vacuum pressure maintained in the outer seal chamber **66**. Using this technique, a leak in the middle seal **48** will result in a change in the vacuum pressure 10 which is detected by the vacuum pressure probes **78** in the inner seal chamber **64**.

The use of the outer bag **94** in combination with the H-shaped seal area **82** provides further protection against loss of compaction pressure in the event of seal leaks. The H-shaped seal area **82** along with the inner and outer bag seal **98, 100** form double seals with the outer bag **94** that are independent of the outer seal **46**, middle seal **48** and 15 inner seal **50**. Thus, in the event a loss of vacuum pressure within the bag vacuum chamber **92**, the vacuum pressure is nevertheless maintained within the outer bag vacuum chamber **96** and within the area **93** beneath the outer vacuum bag **94**. Consequently, the outer vacuum bag **94** maintains the required compaction pressure against the composite skin layup **56**.

20 Figure **12** illustrates the overall steps of a method of sealing and testing multiple segments of a mandrel in an autoclave environment. At step **112**, an inner bag vacuum chamber **92** is formed that overlaps the seams **24** of the mandrel segments **22** and an inner seal **50** between the mandrel segments **22**. At **114**, an outer vacuum bag chamber **96** and H-shaped seal area **82** are formed on opposite ends of the inner bag vacuum chamber **92**. 25 At **116**, an outer seal chamber **66** is formed using the H-shaped seal area **82**, an outer seal **46** and a middle seal **48**. At **118**, an inner seal chamber **64** is formed using the middle seal **48** and the inner seal **50**. At **120**, a leak in any one of the inner seal **50**, the middle seal **48** or outer seal **46** is detected. The leak may be affected by sensing a change in vacuum pressure within the inner and outer vacuum bag chambers **92, 96**.

30 Figure **13** illustrates the overall steps of an alternate method of sealing and testing the integrity of seals between at least two tool segments **22**. At step **122**, an inner seal **50**, an outer seal **46** and a middle seal **48** are arranged to form first and second seal chambers,

64, 66 respectively. At 124, a vacuum is applied to each of the first and second seal chambers 64, 66. At 126, a leak is detected any one of the inner seal 50, the outer seal 46 and an middle seal 48 by sensing a change in vacuum pressure within either of the first and second seal chambers 64, 66.

5 Embodiments of the disclosure may find use in a variety of potential applications, particularly in the transportation industry, including for example, aerospace, marine, automotive applications and other application where it is necessary to seal segmented tools, such as those used to autoclave process composite parts. Thus, referring now to Figures 14 and 15, embodiments of the disclosure may be used in the context of an 10 aircraft manufacturing and service method 128 as shown in Figure 14 and an aircraft 130 as shown in Figure 15. Aircraft applications of the disclosed embodiments may include, for example, without limitation, composite shells forming part of barrel-shaped fuselage sections. During pre-production, exemplary method 128 may include specification and 15 design 132 of the aircraft 130 and material procurement 134. During production, component and subassembly manufacturing 136 and system integration 138 of the aircraft 130 takes place. Thereafter, the aircraft 130 may go through certification and delivery 140 in order to be placed in service 142. While in service by a customer, the aircraft 130 is scheduled for routine maintenance and service 144, which may also include modification, reconfiguration, refurbishment, and so on.

20 Each of the processes of method 128 may be performed or carried out by a system integrator, a third party, and/or an operator (e.g., a customer). For the purposes of this description, a system integrator may include without limitation any number of aircraft manufacturers and major-system subcontractors; a third party may include without limitation any number of vendors, subcontractors, and suppliers; and an operator may be 25 an airline, leasing company, military entity, service organization, and so on.

As shown in Figure 15, the aircraft 130 produced by exemplary method 128 may include an airframe 146 with a plurality of systems 148 and an interior 150. Examples of high-level systems 148 include one or more of a propulsion system 152, an electrical system 154, a hydraulic system 156 and an environmental system 158. Any number of 30 other systems may be included. Although an aerospace example is shown, the principles of the disclosure may be applied to other industries, such as the marine and automotive industries.

Systems and methods embodied herein may be employed during any one or more of the stages of the production and service method 128. For example, components or subassemblies corresponding to production process 136 may be fabricated or manufactured in a manner similar to components or subassemblies produced while the 5 aircraft 130 is in service. Also, one or more apparatus embodiments, method embodiments, or a combination thereof may be utilized during the production stages 136 and 138, for example, by substantially expediting assembly of or reducing the cost of an aircraft 130. Similarly, one or more of apparatus embodiments, method embodiments, or a combination thereof may be utilized while the aircraft 130 is in service, for example and 10 without limitation, to maintenance and service 142.

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, "at least one of item A, item B, and item C" may include, without limitation, item A, item A and item B, or item B. This 15 example also may include item A, item B, and item C or item B and item C. The item may be a particular object, thing, or a category. In other words, at least one of means any combination items and number of items may be used from the list but not all of the items in the list are required.

The description of the different illustrative embodiments has been presented for 20 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 illustrative embodiments may provide different advantages as compared to other illustrative embodiments. The embodiment or embodiments selected are chosen and described in order to best explain 25 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. A method for sealing and monitoring multiple segments of a mandrel in an
5 autoclave environment, comprising:

forming an inner bag vacuum chamber overlapping ends and seams of the mandrel segments and an inner seal between the mandrel segments;

10 forming an outer vacuum bag chamber and an H-shaped seal area on opposite ends of the inner bag vacuum chamber;

forming an outer seal chamber using the H-shaped seal area, the inner seal and a middle seal;

15 forming an inner seal chamber using the middle seal and the inner seal; and

20 monitoring the integrity of any of the inner seal, the middle seal and the outer seal.

2. The method of claim 1, further comprising:

25 pressing the inner seal, the middle seal, the outer seal and legs of the H-shaped seal area into grooves within the mandrel segments.

3. The method of either claim 1 or claim 2, wherein forming the outer vacuum bag chamber includes sealing the legs of the H-shaped seal area to the inner and outer vacuum bags.

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4. The method of any one of claims **1** to **3**, wherein forming the outer bag vacuum chamber includes sealing legs of the H-shaped seal area to the inner seal and the middle seal.

5 5. The method of any one of claims **1** to **4**, wherein monitoring the integrity includes sensing a change in vacuum pressure within any of the inner bag vacuum chamber, the inner seal chamber and the outer seal chamber.

6. A substantially air-tight seal arrangement along a seam between first and second
10 tool segments, comprising:

inner, middle and outer seals forming first and second substantially air tight vacuum chambers; and

15 an H-shaped seal area located at opposite ends of the seam and connected to the middle seal and the outer seal.

7. The seal arrangement of claim **6**, wherein:

20 the inner, middle and outer seals extend along a length of the seam, and are arranged in an H-shaped pattern at each of opposite ends of the seam.

8. The seal arrangement of claim **7**, wherein:

25 the first and second tool segments are arranged to form a layup surface, and the H-shaped pattern includes first and second legs adapted to be sealed to first and second vacuum bags covering the layup surface.

9. The seal arrangement of any one of claims **6** to **8**, wherein the inner, the middle
30 and the outer seals are spaced apart from, and extend longitudinally along the seam.

10. The seal arrangement of any of one claims **6** to **9**, wherein:

the inner and middle seals are spaced apart from each other and form the first vacuum chamber, and

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the middle and outer seals are spaced apart from each other and form the second vacuum chamber.

11. The seal arrangement of any one of claims **6** to **10**, wherein:

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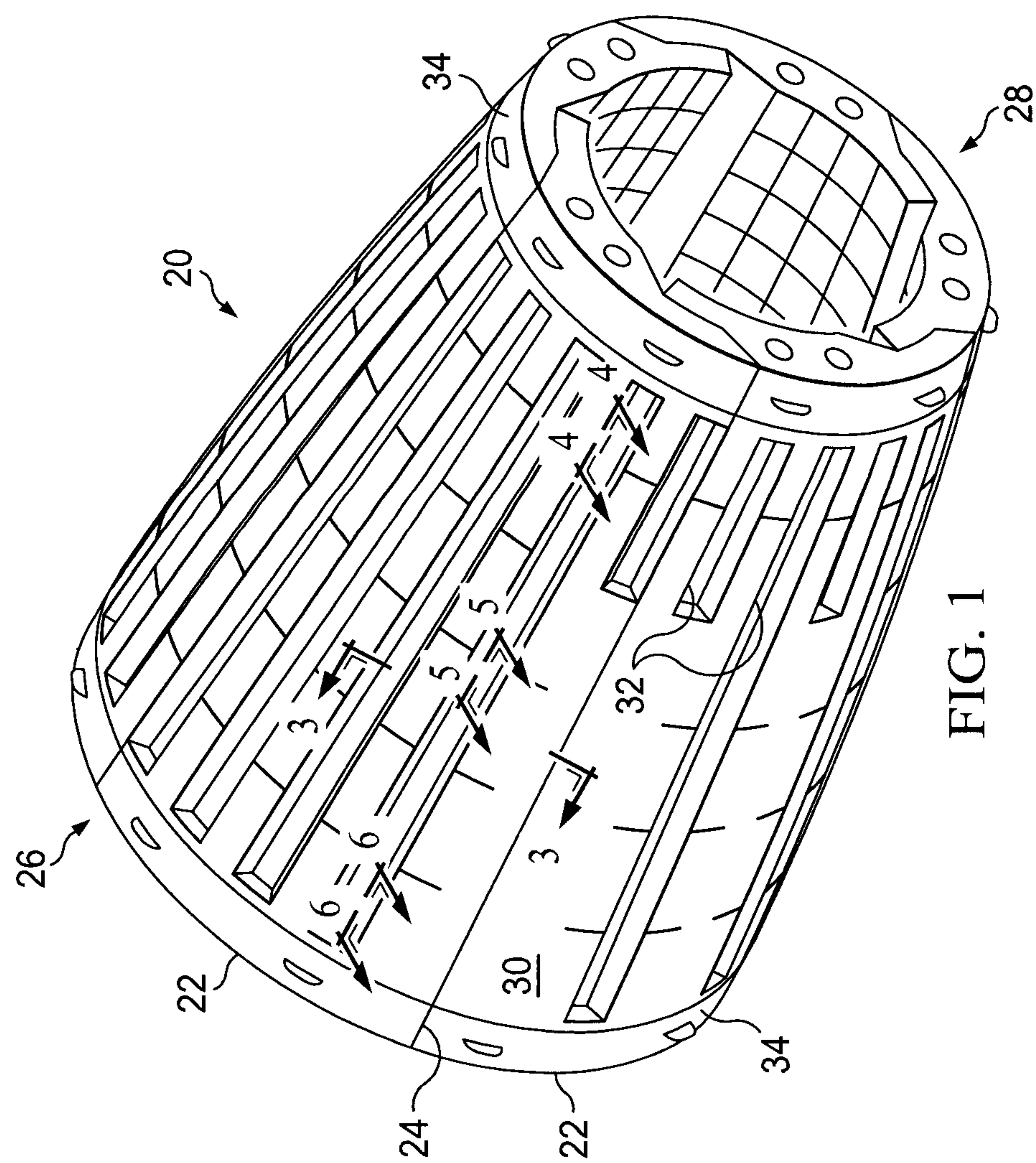
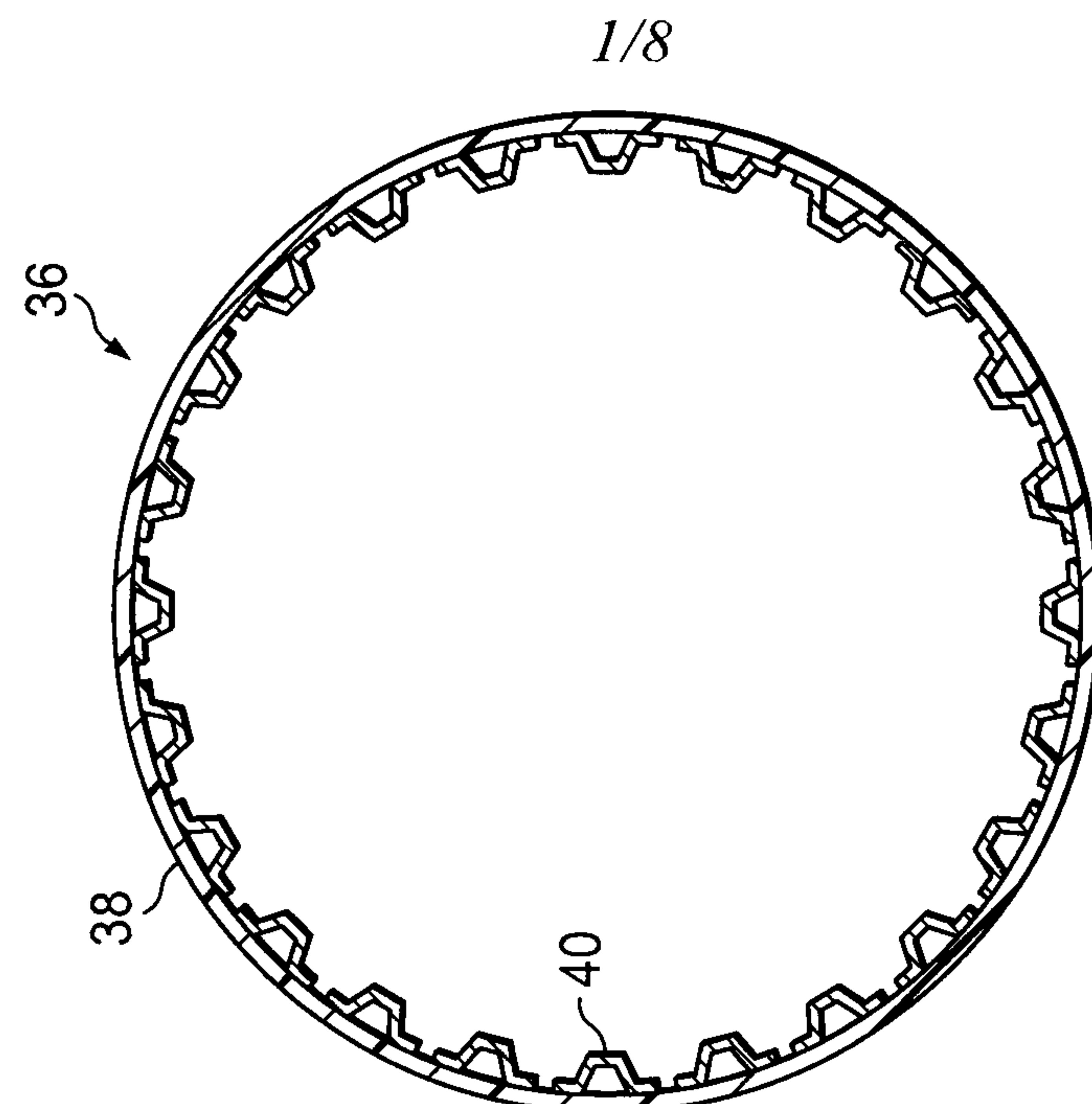
each of the first and second vacuum chambers is adapted to be coupled with a vacuum source and a vent for independently testing the inner, middle and outer seals for air leaks.

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12. The seal arrangement of any one of claims **6** to **11**, further comprising:

first and second vacuum probes are respectively sensing vacuum pressure in the first and second vacuum chambers.

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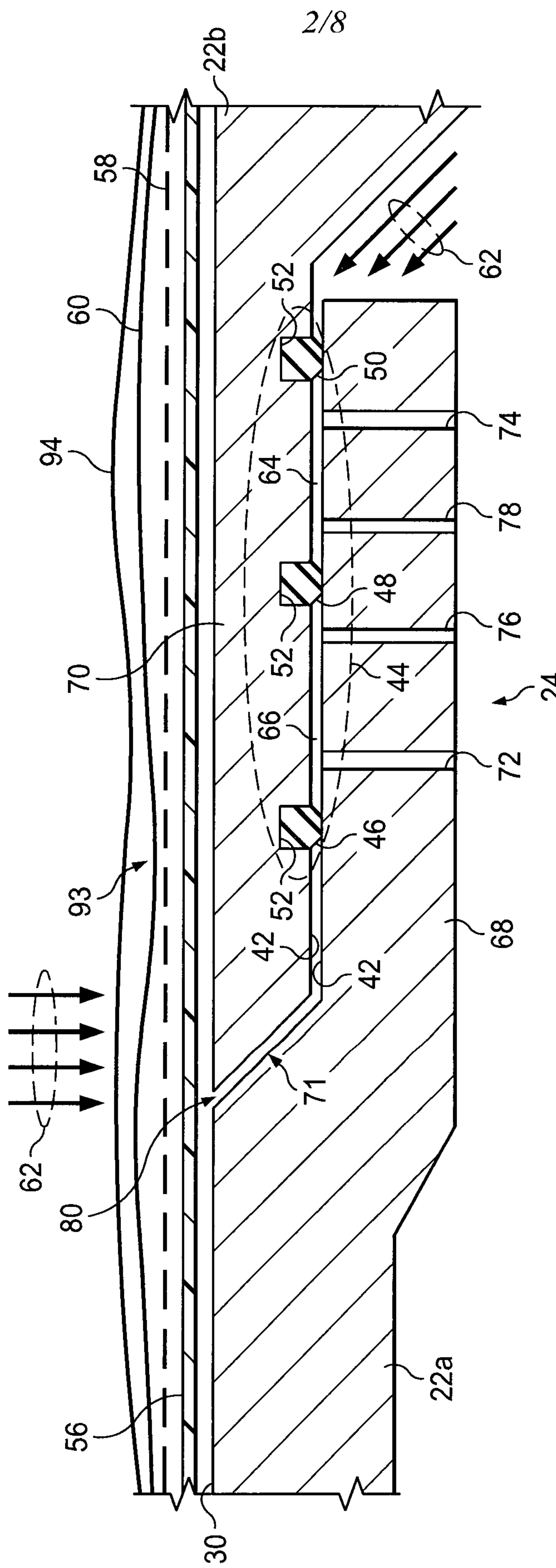


FIG. 3

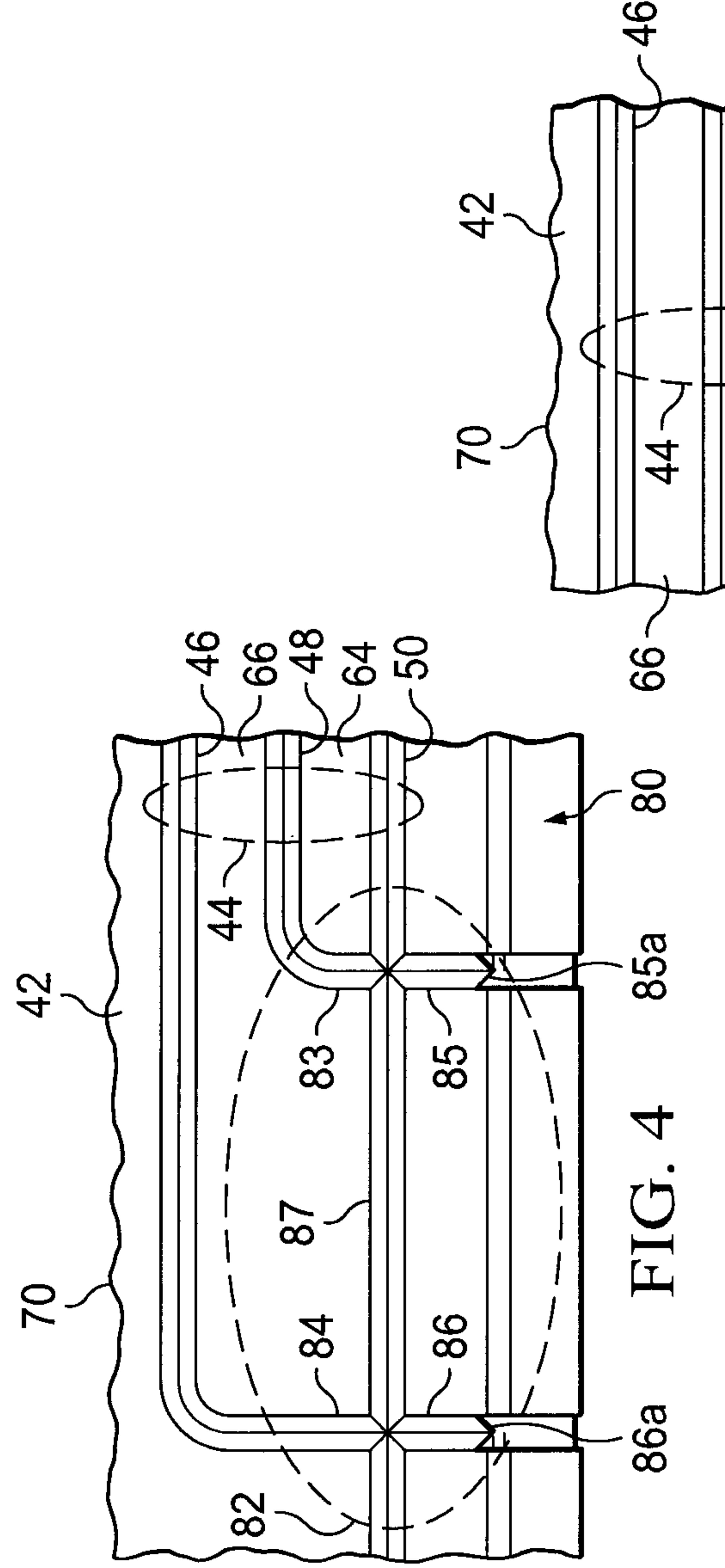
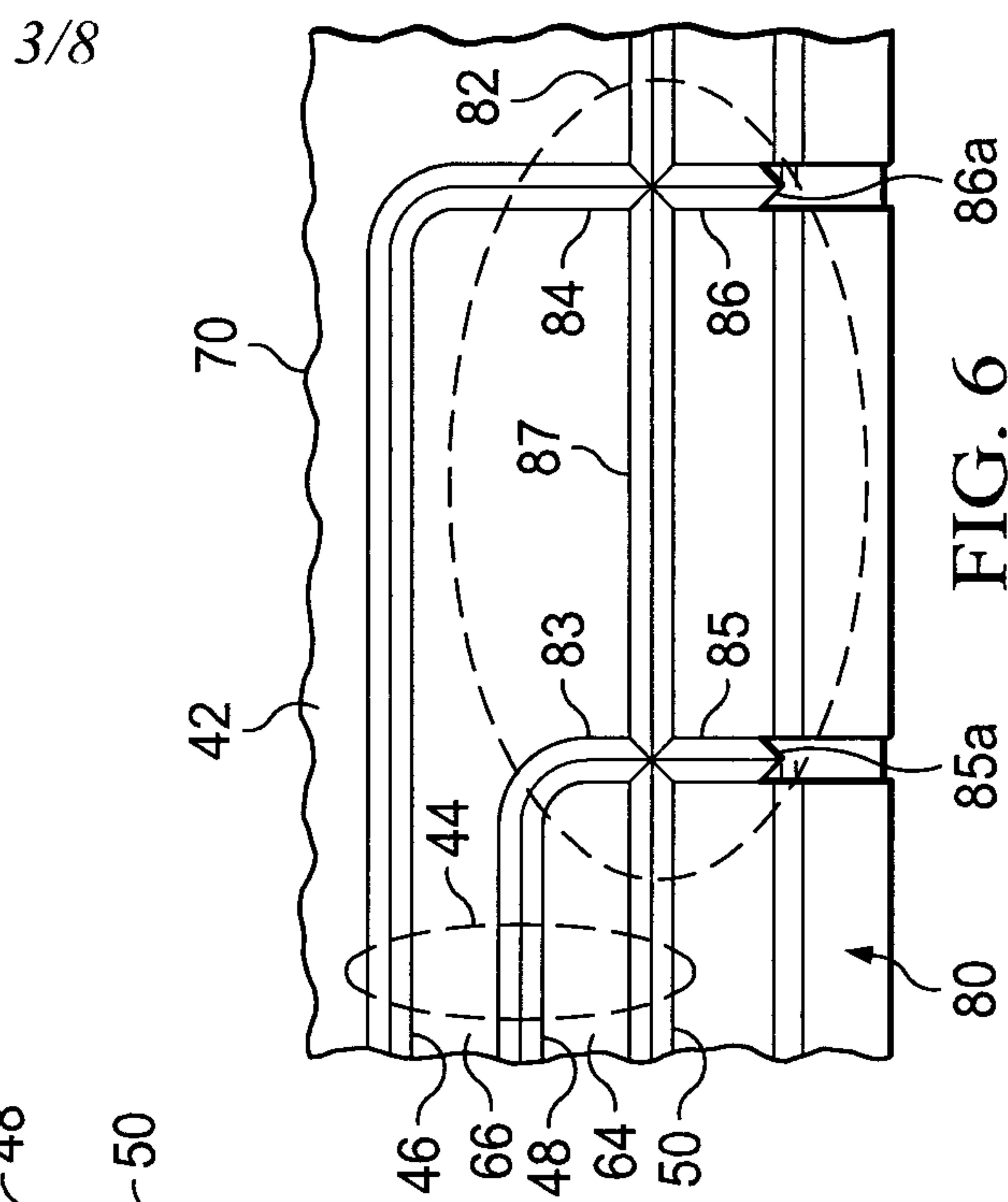
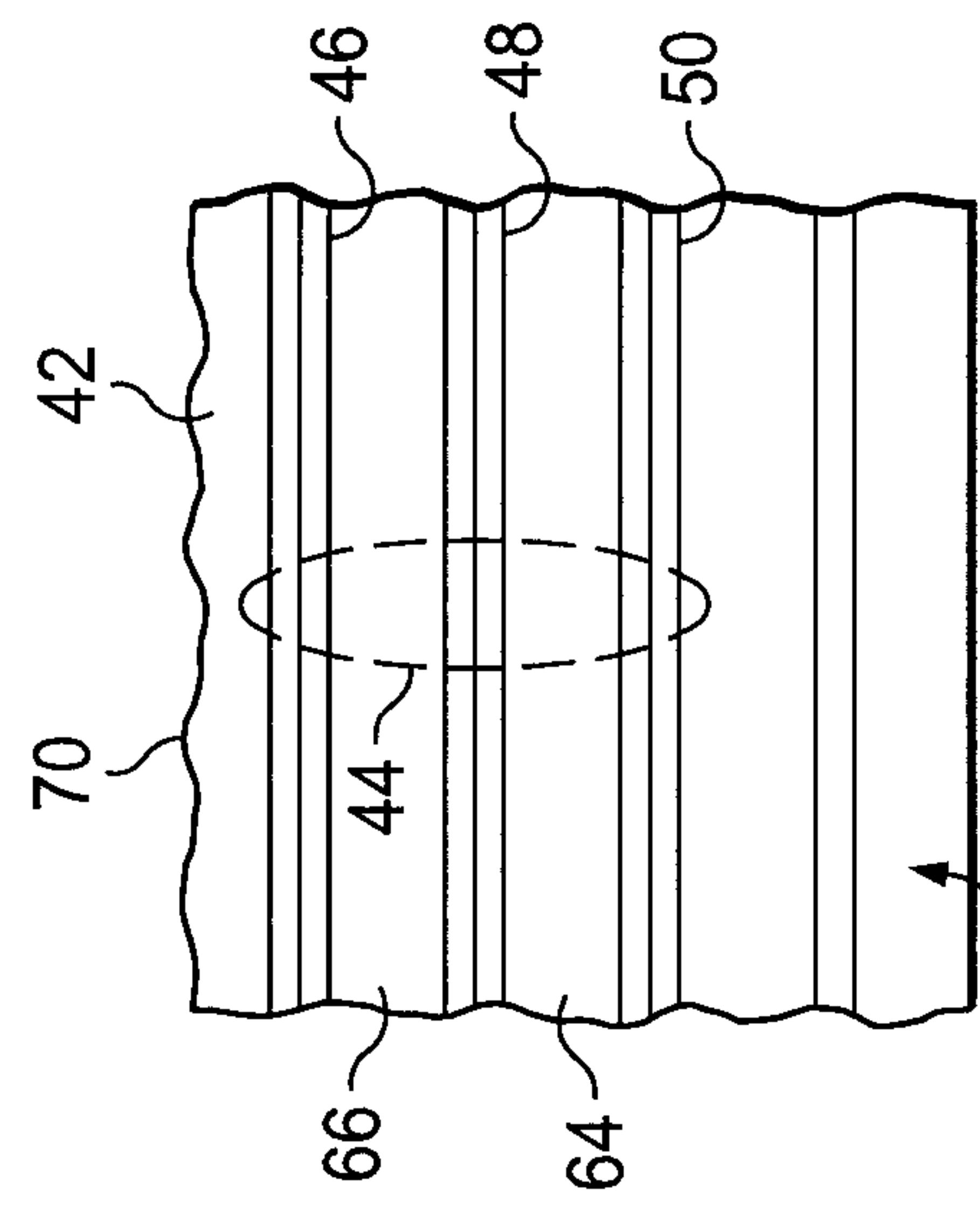


FIG. 5



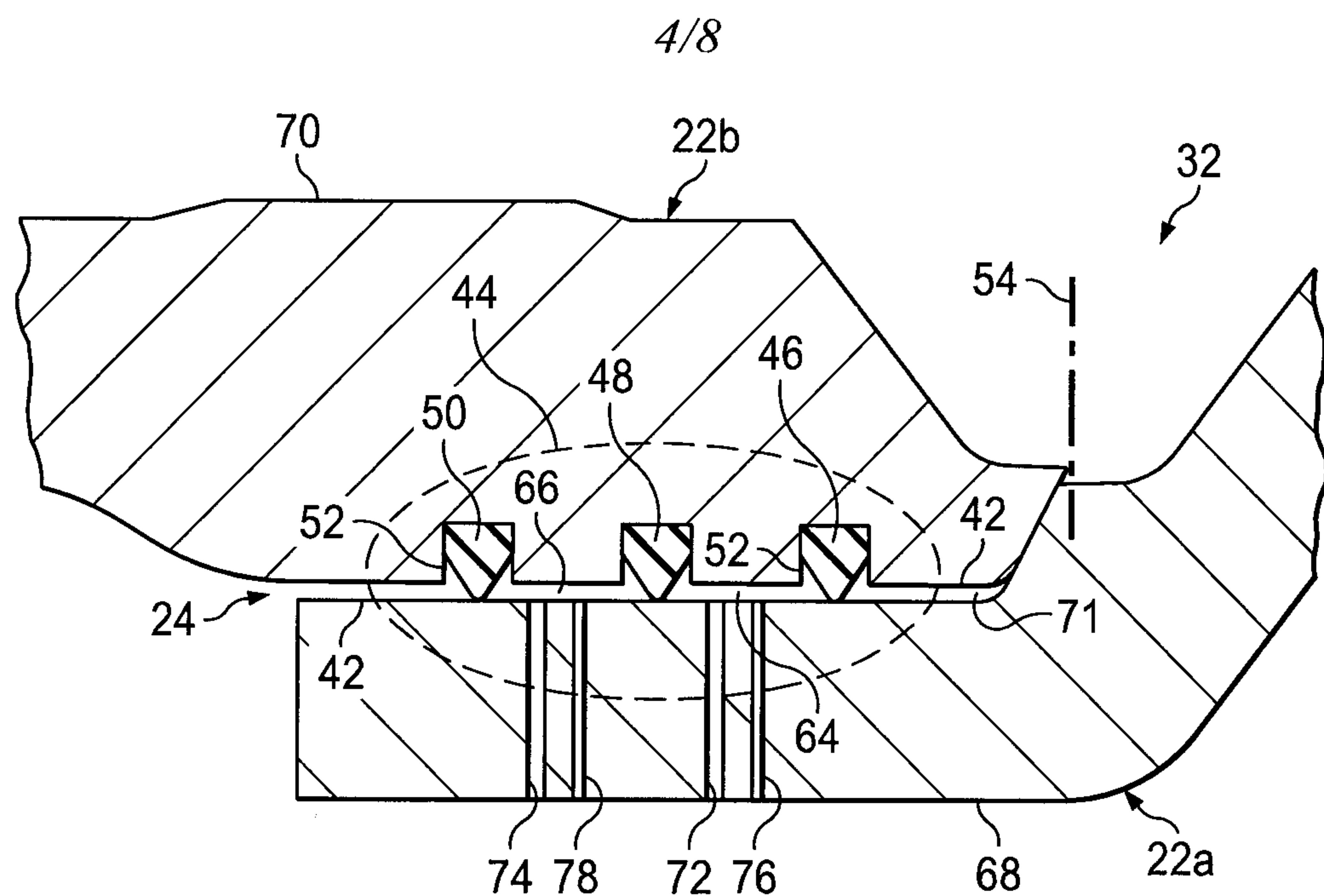


FIG. 7

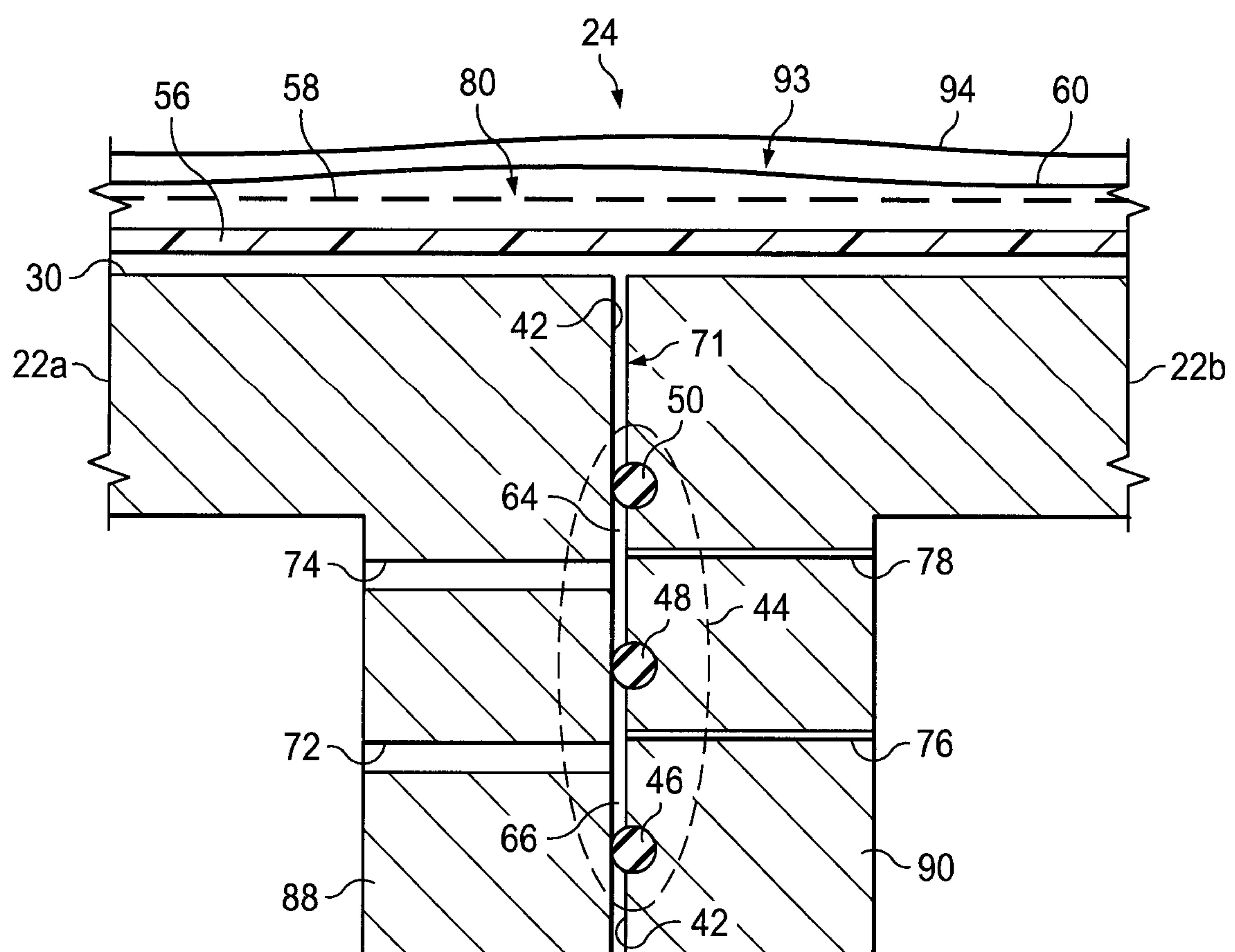
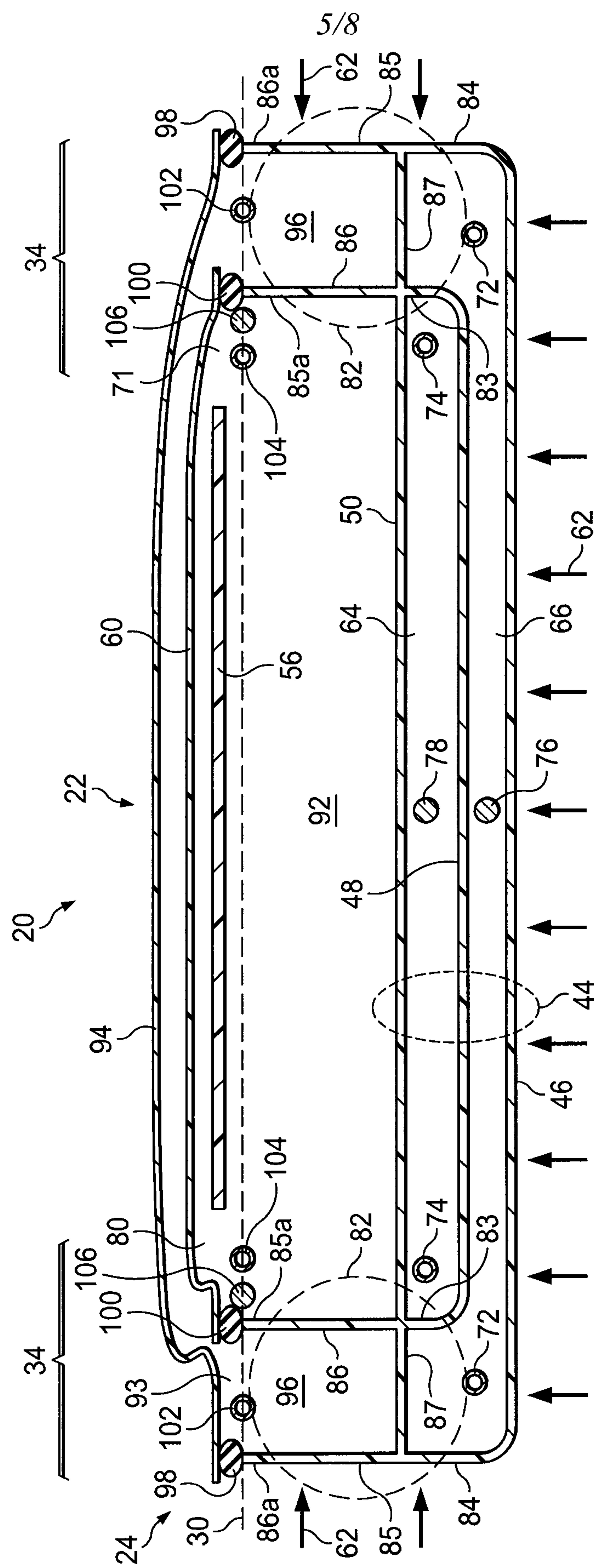


FIG. 8



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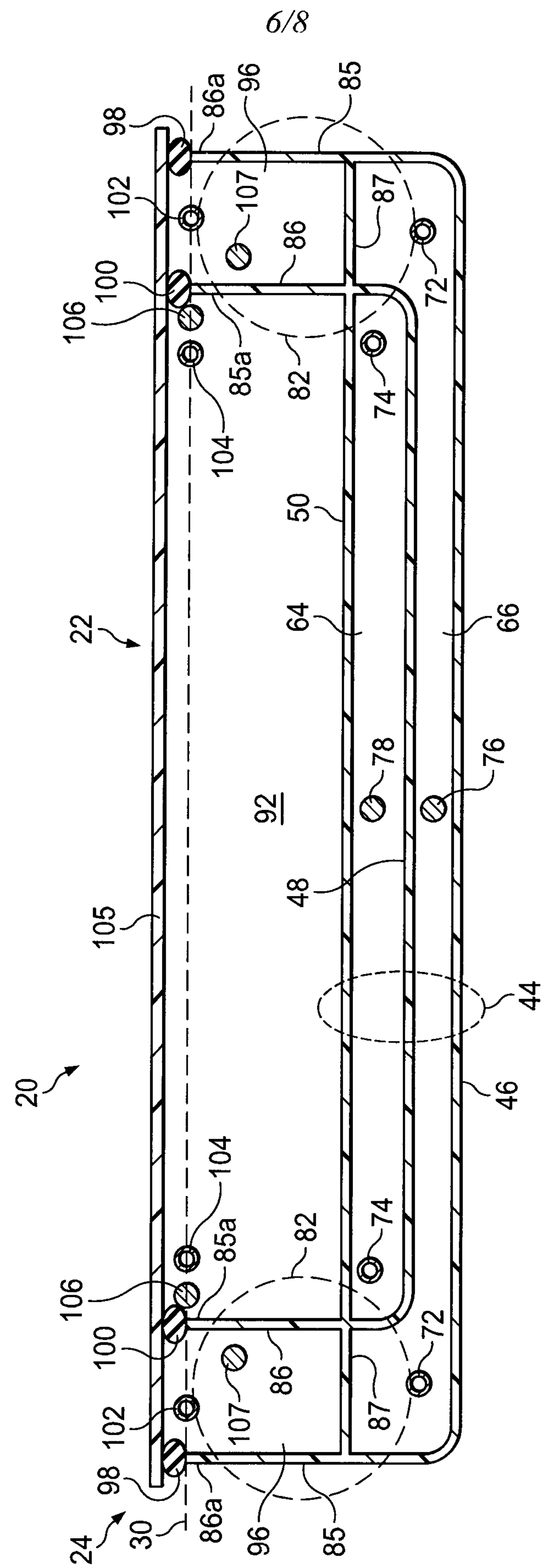
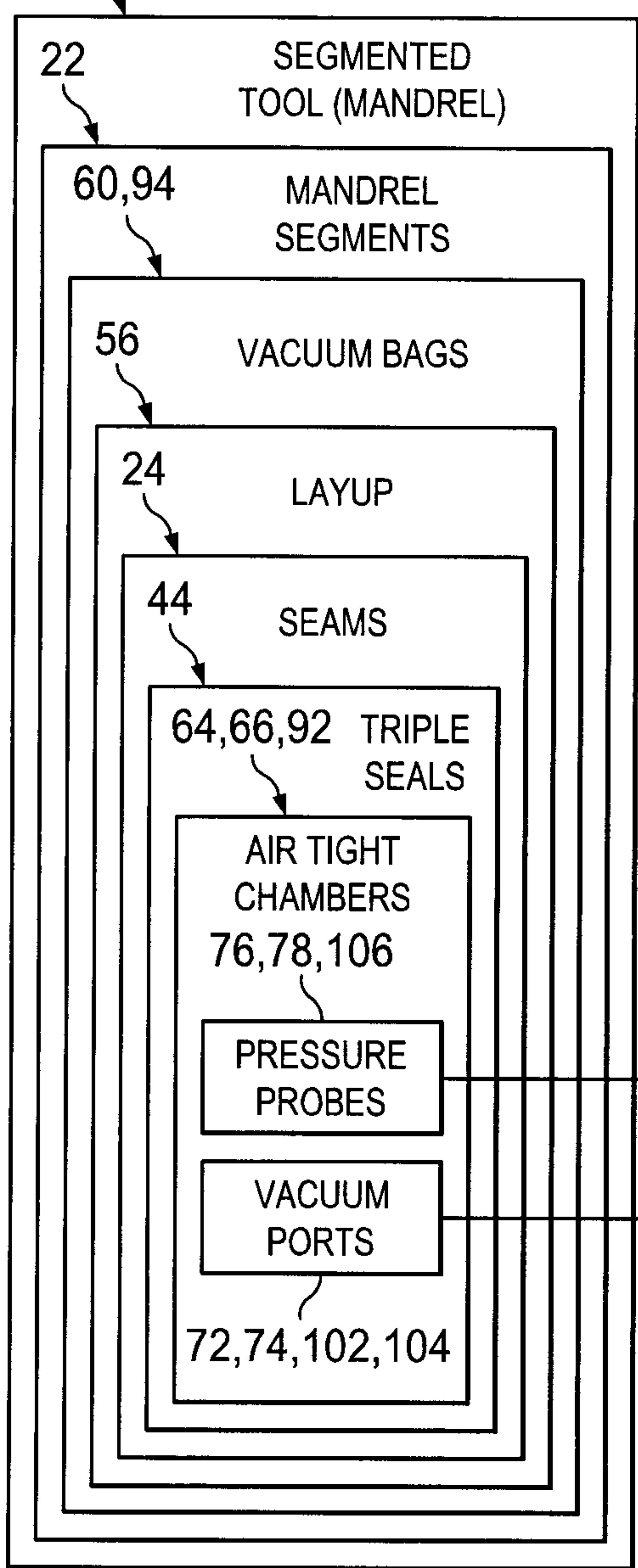


FIG. 10

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FIG. 11



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FIG. 12

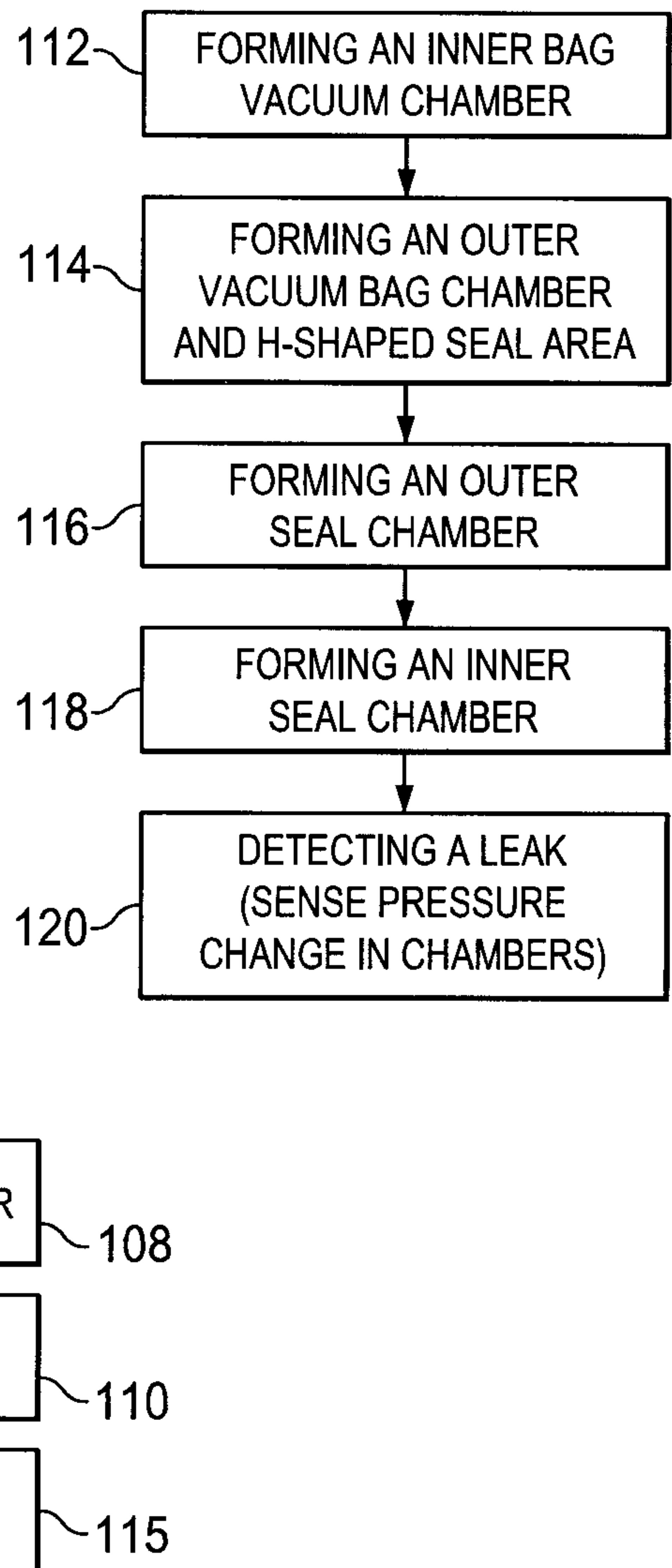
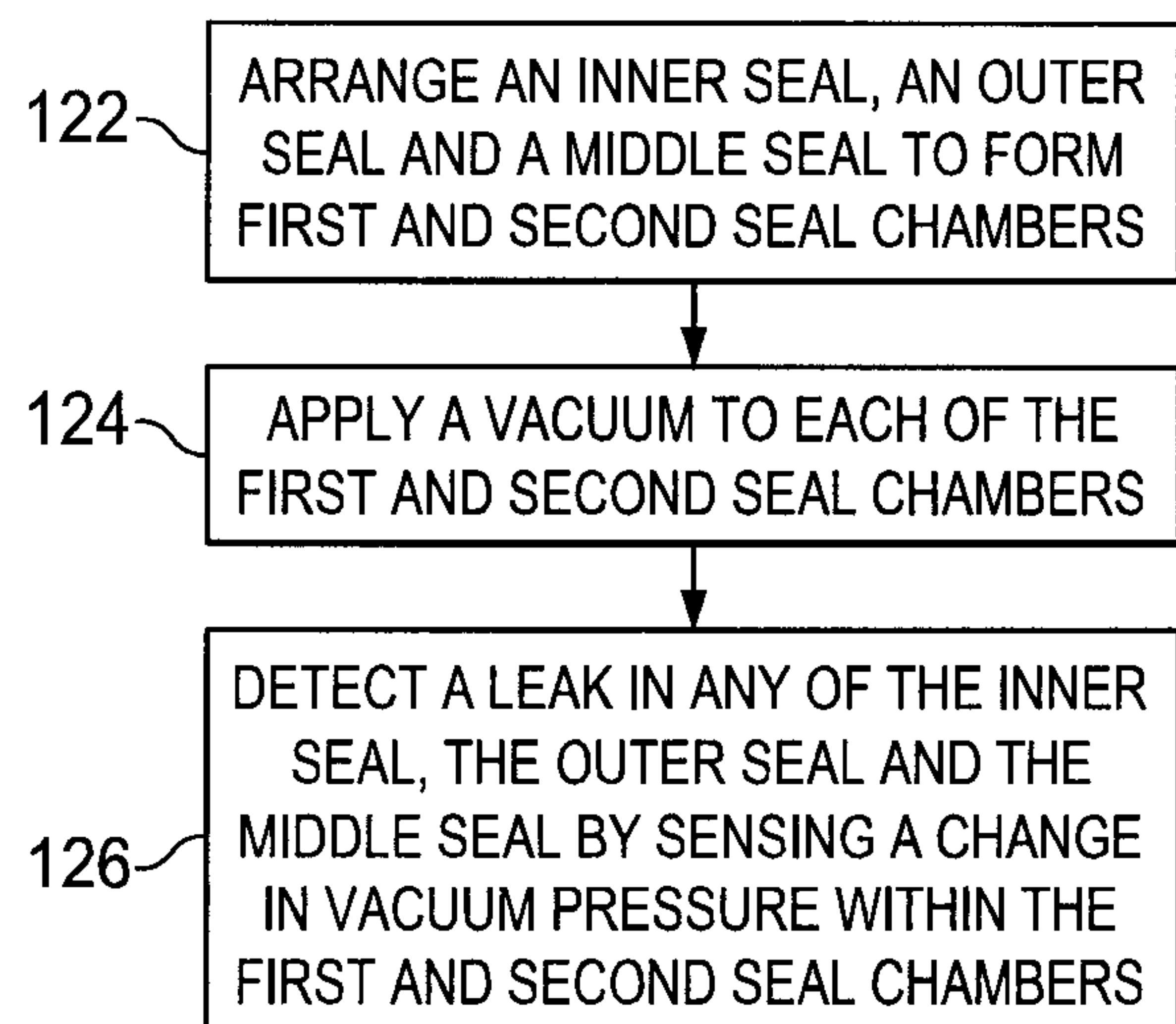
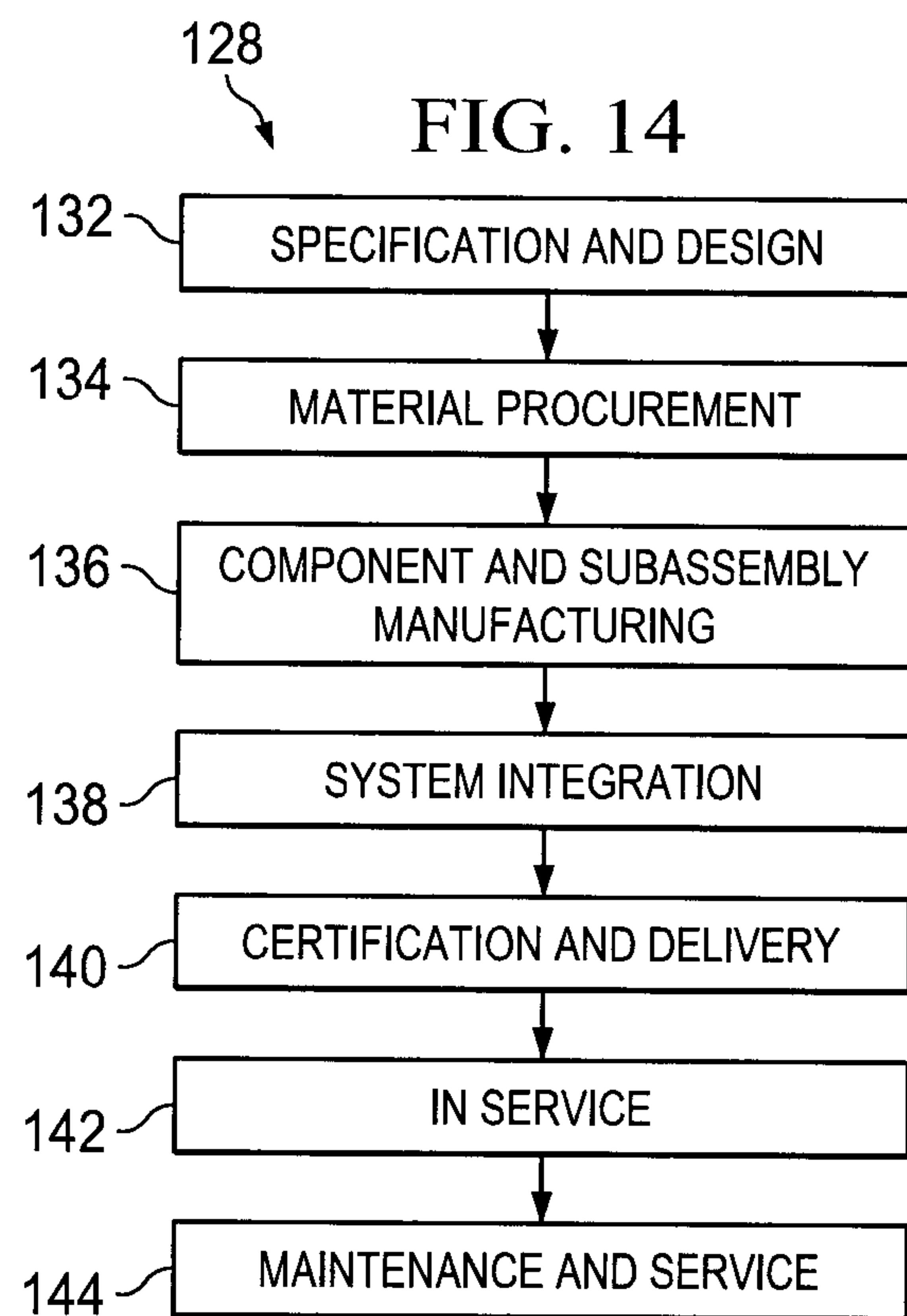


FIG. 13



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FIG. 15

