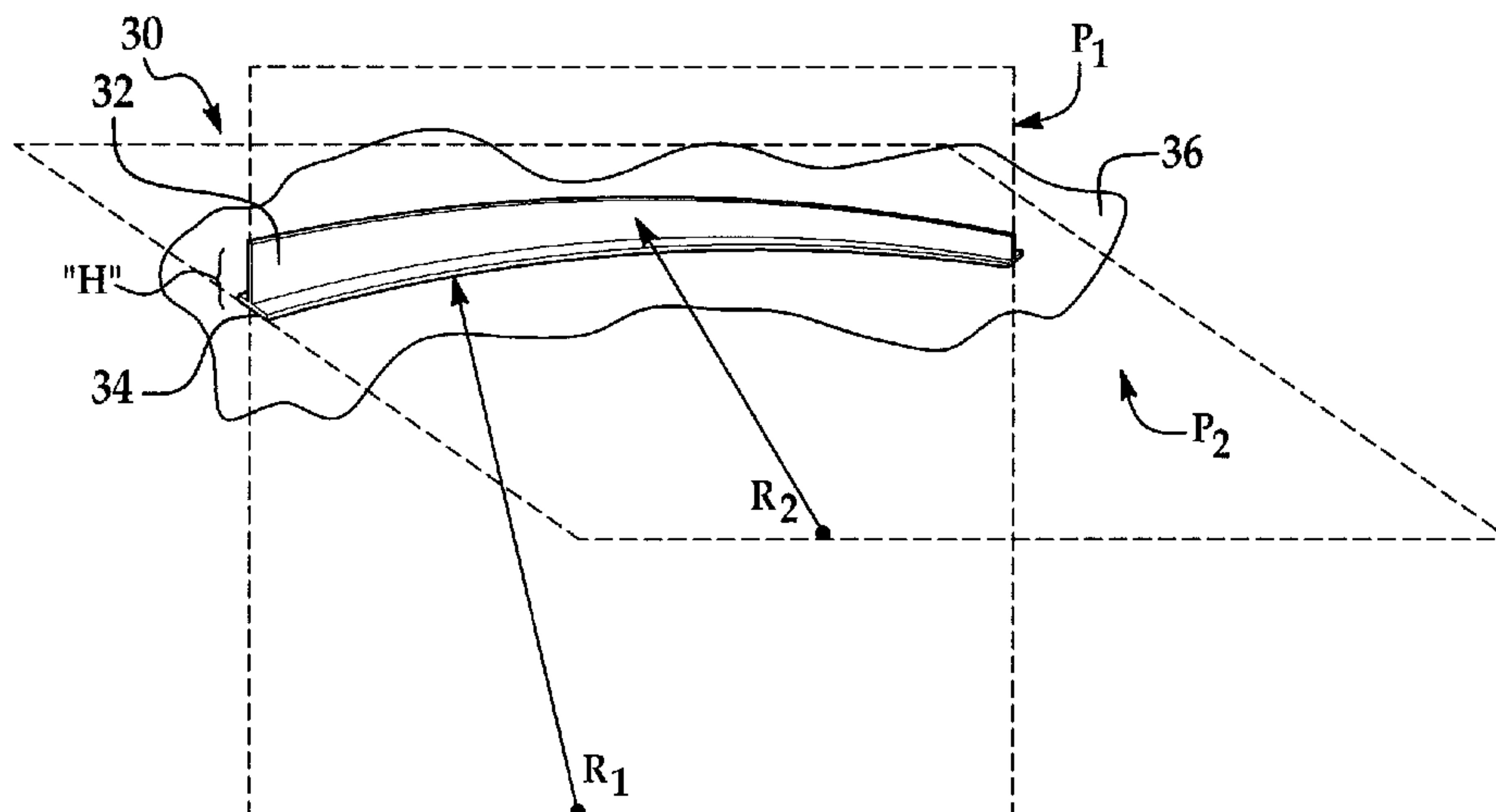




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(54) Titre : PROCEDE ET APPAREIL SERVANT A FABRIQUER DES RAIDISSEURS PROFILES EN MATERIAUX COMPOSITES  
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(57) Abrégé/Abstract:

A contoured composite part is made by assembling a preform charge, including aligning a plurality of plies along a preselected contour. The assembled aligned preform charge is then placed in a forming tool, where the charge is formed and cured.

ABSTRACT OF THE DISCLOSURE

A contoured composite part is made by assembling a preform charge, including aligning a plurality of plies along a preselected contour. The assembled aligned preform charge is 5 then placed in a forming tool, where the charge is formed and cured.

METHOD AND APPARATUS FOR MAKING  
CONTOURED COMPOSITE STIFFENERS

TECHNICAL FIELD

5 This disclosure generally relates to the fabrication of composite parts, and deals more particularly with a method and apparatus for making contoured composite stiffeners.

BACKGROUND

10 Composite structural members such as stiffeners may be used in a variety of applications to increase the strength and/or rigidity of assemblies. For example, in the aircraft industry, structural stiffeners such as stringers may be used to strengthen a fuselage. The stringers may be contoured 15 along their length in order to conform to curvatures in the fuselage. In some areas of the fuselage, the stringers may have compound contours along their lengths.

Composite stringers having compound contours of the type 20 described above may be fabricated by laying up multiple plies of composite pre-preg over a tool having compound contours substantially matching those of the finished part. The layup may be formed to shape and cured using vacuum bag and autoclave processing. Fabrication techniques using pre-preg 25 may have disadvantages in some applications. For example, in order to achieve the desired stringer contours, one or more of

the pre-preg plies may require cutting, darting and/or splicing, which may add weight to the fuselage and/or cost.

Other techniques may be used to fabricate contoured  
5 stringers, such as resin infusion of dry fiber preforms. However, resin infusion may require the use of closed molds which need preparation and later cleanup after the part has been molded to shape. Moreover, alignment of the preform with resin distribution media and permeable parting films may be  
10 difficult without the use of stitching and/or tackifiers. Also, it may be difficult to control fiber angles in fiber preforms using known resin infusion techniques. Variations in fiber angles may result in undesired performance characteristics in the finished part.

15

Accordingly, there is a need for a method and apparatus for fabricating composite structural members having compound contours that reduce tool handling and which facilitate alignment of composite charges to better match tool contours.  
20 There is also a need for a method and apparatus as described above which may substantially eliminate the need for clean up of tooling following part molding, and which may be adapted for resin infusion processing using open molds.

## SUMMARY

The disclosed embodiments provide a method and apparatus for fabricating composite structural members, such as stringers, having compound contours. The use of contour 5 preform braiding with open bagged tooling provides uniform cure pressure for resin infusion curing to produce cured stringers with continuous fibers. In one embodiment, dual vacuum bags are used to provide pressure across the flanges of a stringer, and enabling them to be held in intimate contact 10 with the mold surface while reducing the chance of bag leaks. Near net molding of stringers may be achieved without the need for stitching, tackifiers and tool handling. The use of an alignment tool for pre-aligning components of a preform fiber charge reduces the need for handling the preform, which may 15 result in improved control over fiber angle and/or thickness of the finished part. The use of fiber preforms that are braided, including biaxial and triaxial braids, may allow the preform to better conform to and accommodate different and changing three dimensional contours and radii during layup.

20

The apparatus includes a preform charge assembly tool and a preform forming tool. A contoured, braided preform is assembled in the assembly tool with resin distribution media and permeable parting films. The assembly tool sets the 25 desired contour with changing radii for the desired part. The assembled and pre-aligned preform charge is transferred from

the assembly tool into an envelope vacuum bag held in a forming tool where a bladder-actuated mandrel clamps a web or blade portion of the preform, following which one or more flanges of the preform are folded to form stringer flanges. A 5 radius filler and cap plies are added, as desired, the envelope vacuum bag is sealed, and a second vacuum bag is installed. The charge is then infused with resin. Following resin infusion and curing, the part is removed from the open mold and trimmed to the desired cross section and lengths.

10

In accordance with one disclosed embodiment, a method is provided of making a contoured composite part. The method comprises assembling a charge, including aligning a plurality of plies along a preselected contour and transferring aligned 15 charge to a forming tool. The method further comprises forming the charge in the forming tool and curing the formed charge. Assembling the charge may include placing at least one fiber preform on an assembly tool, and aligning the plies may include using the assembly tool to align the fiber preform 20 along the preselected contour. After being assembled on the assembly tool, a portion of the charge is clamped following which an unclamped portion of the charge is then inserted into the forming tool. The method may further comprise infusing the fiber preform with resin after the aligned charge has been 25 transferred to the forming tool. The method may also comprise placing a first vacuum bag over the forming tool before the

aligned charge is transferred to the forming tool, placing a second vacuum bag over at least a portion of the fiber preform contained within the first vacuum bag, and infusing the fiber preform with resin introduced into the first vacuum bag. The 5 method may further comprise maintaining the alignment of the plies in the charge by clamping the plies together while in the assembly tool and keeping them clamped until they have been clamped in the forming tool.

10 According to another disclosed embodiment, a method is provided of making a composite structural member having a web and at least one flange. The method comprises assembling a multi-ply charge having at least one fiber reinforcement and clamping a first web portion of the charge in a tool. The 15 method further comprises forming a second flange portion of the charge while the first web portion is clamped in the tool, and curing the formed charge. Assembling the charge may include aligning the plies relative to each other along a preselected contour, and clamping the aligned plies together.

20 According to a further embodiment, apparatus is provided for making a composite structural member having at least one contour. The apparatus comprises an assembly tool for assembling a plurality of plies forming a charge, and a forming tool for forming the structural member. The assembly 25 tool includes a contoured alignment guide for aligning the

plies along a contour and a clamping mechanism for clamping the pre-aligned plies together. The forming tool includes a pair of relatively moveable mandrels between which the assembled charge may be clamped. The forming tool includes a 5 base, wherein the mandrels are relatively movable on the base toward and away from each other to clamp the charge therebetween. The mandrels include tool surfaces over which at least a portion of the clamped charge may be formed. The forming tool may further include an inflatable bladder for 10 applying clamping pressure to one of the mandrels. The apparatus may also comprise the first vacuum bag covering the forming tool, and a second vacuum bag adapted to cover the formed charge, the web of which is clamped on the forming tool. Each of the mandrels includes a contoured clamping 15 surface for forming a contour into the charge.

According to still another embodiment, apparatus is provided for making a composite member having a web with a compound contour and at least one flange. The apparatus 20 comprises an assembly tool for assembling pre-aligning a charge along a first contour, and a forming tool. The forming tool includes a base and a pair of contoured mandrels on the base between which a web portion of the charge may be clamped and formed along the second contour. At least one of the 25 mandrels includes a tool surface onto which a flange portion of the clamped charge may be formed.

According to still another embodiment, there is provided a method of making a contoured composite part, the method comprising: assembling a charge, including aligning a plurality of plies along a preselected contour; placing a 5 first vacuum bag over a forming tool before the charge is transferred to the forming tool and sealing the first vacuum bag to the forming tool; transferring the charge to the forming tool; forming the charge on the forming tool; placing a second vacuum bag over the charge and sealing the second 10 vacuum bag to the forming tool; applying first and second vacuums respectively to the first and second vacuum bags; infusing the charge with resin introduced into the first vacuum bag; and curing the charge.

15 According to still another embodiment, there is provided an apparatus for making a composite structural member having at least one contour, the apparatus comprising: an assembly tool for assembling a plurality of plies forming a charge; a forming tool for forming the charge, the forming tool 20 including a pair of relatively movable mandrels between which a first portion of the charge may be clamped; a first vacuum bag adapted to cover the forming tool; a second vacuum bag adapted to cover the charge clamped on the forming tool and hold at least a second portion of the charge against the 25 forming tool; first and second seals for sealing the first and second vacuum bags to the forming tool; and a resin supply

line for introducing resin into the first vacuum bag and infusing the charge.

According to still another embodiment, there is provided  
5 an apparatus for making a composite structural member having a web and having at least one contour, the apparatus comprising: an assembly tool for assembling a plurality of plies forming a charge, wherein the assembly tool comprises: an alignment guide having an adjustable contour against which the plies of  
10 the charge may be aligned and contoured; and a spacer adapted to be placed on the charge and having a width substantially equal to a height of the web; and a forming tool for forming the charge, the forming tool including a pair of relatively movable mandrels between which the charge may be clamped.

15

According to still another embodiment, there is provided an apparatus for making a composite member with a compound contour and having a web and at least one flange, the apparatus comprising: an assembly tool for pre-aligning a  
20 multi-ply charge along a first contour of the compound contour, the assembly tool comprising: a surface on which the charge may be assembled; an alignment guide having an adjustable contour against which the plies of the charge may be aligned and contoured; a spacer adapted to be placed on the charge and having a width substantially equal to a height of  
25 the web; and at least one clamp for clamping the aligned and

contoured plies together with the spacer, and grooves to allow clamping access to both sides of the charge; and a forming tool including a base and a pair of contoured mandrels on the base between which a web portion of the charge may be clamped  
5 and formed along a second contour of the compound contour.

According to still another embodiment, there is provided an apparatus for making a compound contoured composite stringer for aircraft, the stringer having a web and a flange,  
10 the apparatus comprising: an alignment and assembly tool, including: a flat surface on which a flat charge may be placed; an alignment fence having a first contour corresponding to one of the contours of the stringer and against which the charge may be aligned; and a web height spacer for establishing the height of the web; a plurality of clamps for clamping the charge and adapted to abut the web height spacer; a forming and cure tool, including: a tool base having a contour which largely matches the first contour of the alignment fence on the alignment and assembly tool, the  
15 tool base including an assembly of a base plate and spaced apart curved blocks; and a pair of mandrels relatively slideable on the tool base toward and away from each other, the mandrels including a first set of opposing surfaces having a second contour corresponding to another one of the contours of the stringer and for clamping a web portion of the charge  
20 therebetween, the mandrels further including a second set of  
25

surfaces onto which a flange portion of the charge may be formed; a first bag covering the charge; a second bag covering the charge and the first bag; first and second seals for sealing the first and second bags to the forming and cure 5 tool; a resin infusion inlet for allowing resin to flow into the charge within the first bag; and at least one resin outlet for allowing resin to escape from the charge.

According to still another embodiment, there is provided 10 a method of making a compound contoured composite blade stringer for aircraft, the method comprising: placing a resin distribution media on an assembly tool; placing a preform on the assembly tool covering the resin distribution media to form a preform charge; aligning the resin distribution media 15 and the preform charge relative to each other and along an alignment guide having a first contour; placing a blade height spacer over the preform charge; clamping a flange portion of the charge to maintain the alignment of the charge, including using the blade height spacer to control placement of clamps 20 on the charge, to form a clamped charge; installing an inner vacuum bag over a forming tool; applying a first vacuum to a forming tool side of the inner vacuum bag and transferring the clamped charge to the forming tool; clamping a web portion of the charge in the forming tool, including inflating a bladder 25 and using the inflation of the bladder to move a pair of mandrels into clamping engagement with the charge; removing

the clamps from the flange portion of the charge while the web portion of the charge is clamped between the mandrels; forming a formed charge including a pair of stringer flanges by folding the flange portion of the charge down onto the 5 mandrels; folding the inner vacuum bag back over the formed charge; placing an outer vacuum bag over the inner vacuum bag covering the formed charge; sealing the inner and outer vacuum bags; applying second and third vacuums respectively to the inner vacuum bag and the outer vacuum bag; infusing the 10 preform with resin by introducing resin into the inner vacuum bag to form a resin infused fiber preform; curing the resin infused fiber preform on the forming tool to form a cured stringer; and removing the cured stringer from the forming tool following curing.

A method of making a contoured composite part, comprising:

assembling a charge, including aligning a plurality of plies along a preselected contour;

transferring the assembled aligned charge to a forming

5 tool;

forming the charge on the forming tool; and

curing the formed charge.

The method wherein:

10 assembling the charge includes placing at least one fiber preform on an assembly tool, and

aligning the plies includes using the assembly tool to align the fiber preform along the preselected contour.

15 The method further comprising:

infusing the fiber preform with resin after the assembled aligned charge has been transferred to the forming tool.

The method further comprising:

20 placing a first vacuum bag over the forming tool before the assembled aligned charge is transferred to the forming tool;

placing a second vacuum bag over the fiber preform; and

infusing the fiber preform with resin introduced into the

25 first vacuum bag.

The method further comprising:

maintaining the alignment of the plies in the charge by clamping the plies together after the charge has been assembled.

5

The method further comprising:

clamping a first portion of the assembled aligned charge in the forming tool, and

wherein forming the charge includes forming a second portion of the charge on the forming tool while the first portion is clamped.

A contoured composite part made by the method.

15 A method of making a composite structural member having a web and at least one flange, comprising:

assembling a multi-ply charge having at least one fiber reinforcement;

clamping a first web portion of the charge in a tool;

20 forming a second flange portion of the charge while the first web portion is clamped in the tool; and

curing the formed charge.

The method wherein assembling the charge includes:

25 aligning the plies relative to each other along a preselected contour, and

clamping the aligned plies together.

The method wherein assembling the charge includes pre-aligning the plies relative to each other, and the method further 5 comprises:

transferring the charge containing the pre-aligned plies from an assembly tool to a forming tool;  
clamping a portion of the charge in the forming tool; and  
using the forming tool to form the charge.

10

The method wherein clamping a portion of the charge in the forming tool includes:

placing the portion of the charge between a pair of mandrels, and  
15 displacing one of the mandrels toward the other mandrel by inflating a bladder.

The method further comprising:

20 placing a first vacuum bag over the tool;  
placing a second vacuum bag over the formed charge;  
drawing a vacuum in the second bag; and  
infusing the charge with resin by introducing resin into  
the first vacuum bag.

25 The method wherein assembling the charge includes:

stacking plies on a surface, including placing at least one braided fiber preform on the surface and aligning the fiber preform along against a contoured fence.

5 A composite structural member made by the method.

An apparatus for making a composite structural member having at least one contour, comprising:

an assembly tool for assembling a plurality of plies  
10 forming a charge; and

a forming tool for forming the charge, the forming tool including a pair of relatively movable mandrels between which the assembled charge may be clamped.

15 The apparatus wherein the assembly tool includes:

a contoured alignment guide for aligning the plies along a contour, and

a clamping mechanism for clamping the aligned plies together.

20

The apparatus wherein the forming tool includes a substantially vacuum tight base having pass-throughs adapted to receive for vacuum, compressed air and resin lines,

the mandrels are relatively moveable on the base toward  
25 and away from each other, and

the mandrels include tool surfaces over which at least a portion of the clamped charge may be formed.

5 The apparatus wherein the forming tool includes an inflatable bladder for applying clamping pressure to one of the mandrels.

The apparatus further comprising:

a first vacuum bag adapted to cover the formed charge;  
10 a second vacuum bag adapted to cover the formed charge clamped on the forming tool and hold at least a portion of the charge against the tool; and  
a resin supply line for introducing resin into the first bag and infusing the charge.

15 The apparatus wherein each of the mandrels includes a contoured clamping surface for forming a contour into the charge.

An apparatus for making a composite member having a web with a 20 compound contour and at least one flange, comprising:

an assembly tool for pre-aligning a charge along a first contour; and  
a forming tool including a base and a pair of contoured mandrels on the base between which a web portion of the charge 25 may be clamped and formed along a second contour.

The apparatus wherein at least one of the mandrels includes a tool surface onto which a flange portion of the clamped charge may be formed.

- 5 The apparatus wherein the assembly tool includes:
  - a surface on which a multi-ply charge may be assembled,
  - an alignment guide having an adjustable contour against which the plies of the charge may be aligned and contoured,
  - a spacer adapted to be placed on the charge and having
- 10 width substantially equal to the height of the web,
  - at least one clamp for clamping the aligned and contoured plies together with the spacer, and
  - grooves to allow clamping access to both sides of the charge.
- 15 A method of making a compound contoured composite blade stringer for aircraft, comprising:
  - placing a resin distribution media on an assembly tool;
  - placing a flat braided fiber preform on the assembly tool
- 20 covering the resin distribution media to form a pre-form charge;
  - aligning the resin distribution media and the preform charge relative to each other and along an alignment guide having a first contour;
- 25 placing a blade height spacer over the pre-form charge;

- clamping a flange portion of the charge to maintain the alignment of the charge, including using the blade height spacer to control the placement of clamps on the charge;
- installing an inner vacuum bag over a forming tool;
- 5 transferring the clamped charge to the forming tool;
- clamping a web portion of the charge in the forming tool, including inflating a bladder and using the inflation of the bladder to move a pair of mandrels into clamping engagement with the charge;
- 10 removing the clamps from the flange portion of the charge while the web portion of the charge is clamped between the mandrels;
- forming a pair of stringer flanges by folding the flange portion of the charge down onto the mandrels;
- 15 folding the inner bag back over the formed charge;
- placing an outer bag of the inner bag covering the charge;
- sealing the inner and outer bags;
- applying first and second vacuums respectively to the
- 20 inner and outer bags;
- infusing the fiber preform with resin by introducing resin into the inner bag;
- curing the resin infused fiber preform on the forming tool; and
- 25 removing the cured stringer from the forming tool following curing.

An apparatus for making a compound contoured composite stringer for aircraft having a web and a flange, comprising:

an alignment and assembly tool, including -

5 a flat surface on which a flat charge may be placed,

an alignment fence having a first contour corresponding to one of the contours of the stringer and against which the charge may be aligned,

10 a web height spacer for establishing the height of the stringer web;

a plurality of clamps for clamping the charge and adapted to abut the web height spacer;

a forming and cure tool, including -

15 a tool base having a first contour which largely matches the contour of the alignment fence on the assembly tool, the tool base including an assembly of a base plate and spaced apart curved blocks,

20 a pair of mandrels relatively slideable on the tool base toward and away from each other, the mandrels including a first set of opposing surfaces having a second contour for clamping a web portion of the charge therebetween, the mandrels further including a second set of tool surfaces onto which a flange portion of the charge may be formed;

a first inner bag covering the formed charge;  
a second bag covering the charge and the first bag;  
first and second seals for sealing the first and second  
bags to the forming and cure tool;  
5 a resin infusion inlet for allowing resin to flow into  
the charge within the first bag; and  
at least one resin outlet for allowing resin to escape  
from the charge.

10 BRIEF DESCRIPTION OF THE ILLUSTRATIONS

FIG. 1 is an illustration of a perspective view of a  
composite stringer having compound contours.

15 FIG. 2 is a functional block diagram of apparatus for  
fabricating the stringer shown in FIG. 1.

FIG. 3 is an illustration of a plan view of an assembly  
tool for assembling a composite charge used to make the  
stringer shown in FIG. 1.

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FIG. 4 is an illustration of a side view of the assembly  
tool shown in FIG. 3.

25 FIG. 5 is an illustration similar to FIG. 3 showing resin  
distribution media having been placed on the assembly tool.

FIG. 6 is an illustration similar to FIG. 5 showing a permeable parting film having been placed over the resin distribution media.

5 FIG. 7 is an illustration similar to FIG. 6 showing a braided fiber preform having been placed over the permeable parting film.

10 FIG. 8 is a view similar to FIG. 7 but showing another permeable parting film having been placed over the fiber preform, and blade height spacers having been actuated.

15 FIG. 9 is an illustration similar to FIG. 8 but showing the preform charge clamps having been installed.

FIG. 10 is an illustration similar to FIG. 8 but showing the use of a continuous blade height spacer.

20 FIG. 11 is an illustration similar to FIG. 10 but showing a magnetic transfer bar having been attached to the clamps.

FIG. 12 is an illustration of a sectional view taken along the line 12-12 in FIG. 9.

FIG. 13 is an illustration of a plan view of one end of the forming tool prior to the installation of the pre-aligned charge and resin infusion components.

5 FIG. 14 is an illustration of a sectional view taken along the line 14-14 in FIG. 13.

FIG. 15 is an illustration similar to FIG. 14 but showing the placement of a first vacuum bag on the forming tool.

10

FIG. 16 is an illustration similar to FIG. 15 but showing the pre-aligned charge being placed in the forming tool, the parting films not shown for clarity.

15

FIG. 17 is an illustration similar to FIG. 16 but showing the bladder having been inflated to clamp the web portion of the charge.

20

FIG. 18 is an illustration similar to FIG. 17 but showing the charge clamps having been removed and a spiral resin inlet wrap having been installed in the tool.

25

FIG. 19 is an illustration similar to FIG. 18 but showing the flange portion of the preform having been formed down onto the mandrels.

FIG. 20 is an illustration similar to FIG. 19 but showing a radius gap filler having been placed in the charge.

FIG. 21 is an illustration similar to FIG. 20, but 5 showing additional components including a cap charge having been installed.

FIG. 22 is an illustration similar to FIG. 21 but showing an outer bag having been installed, sealed and evacuated.

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FIG. 23 is an illustration of a flow diagram of a method of making a compound contoured composite member.

15

FIG. 24 is an illustration of a flow diagram showing

additional steps of the method illustrated in FIG. 21.

FIG. 25 is an illustration of a flow diagram of another method of making a composite structural member having compound contours.

20

FIG. 26 is an illustration of a flow diagram of aircraft production and service methodology.

25

FIG. 27 is an illustration of a block diagram of an

aircraft.

## DETAILED DESCRIPTION

Referring first to FIG. 1, the disclosed embodiments broadly relate to a method and apparatus for making a curved composite part, such as, for example and without limitation, a compound contoured composite stringer 30. In the illustrated embodiment, the stringer 30 is contoured according to radii  $R_1$ ,  $R_2$ , which respectively oriented in orthogonal planes  $P_1$ ,  $P_2$  however other contouring geometries are possible, and the stringer 30 may be contoured, or partially contoured along only a portion of its length. In other embodiments, the stringer 30 may have only a single contour along its length. In the illustrated embodiment shown in FIG. 1,  $R_1$  and  $R_2$  form planar arcs that are substantially constant, however  $R_1$ , and/or  $R_2$  may be vary axially and or laterally such that the stringer 15 30 includes one or more twists along its length. The stringer 30, sometimes referred to as a "blade stringer", includes a web portion 32 and a flange portion 34 which may be joined by any suitable means to a contoured skin 36. The web portion 32, sometimes also referred herein as a "blade", has a height 20 "H". While a blade stringer 30 is illustrated in the exemplary embodiment, the disclosed method and apparatus may be employed to fabricate a variety of other elongate structural members having one or more contours along their length. Also, the disclosed method and apparatus may be 25 employed to fabricate elongate structural members having any

of a variety of cross sectional shapes, including without limitation, "C", "J", and "I" shapes, to name only a few.

FIG. 2 illustrates the primary components of the apparatus for fabricating a composite part such as the stringer 30 shown in FIG. 1. The apparatus broadly comprises an alignment and assembly tool 38 (hereinafter referred to as an assembly tool 38, for simplicity of description), and a forming and cure tool 72 (hereinafter referred to as a forming tool 72, also for simplicity of description). The assembly tool 38 includes a table 40 for supporting the charge 62, and a curved fence 48 on the table 40 that is used to align the components 54, 56, 58, 60 (see FIG. 12) of the charge 62. Once aligned, the components 54, 56, 58, 60 (FIG. 12) of the charge 62 are held between the jaws 67 of a plurality of clamps 68. The positions of the clamps 68 on the charge 62 determine the blade height "H" of the stringer 30 shown in FIG. 1 and are by the amount of extension of plungers 52 which engage at least one of the jaws 67 of the clamps 68.

After the charge 62 has been clamped by the clamps 68, a suitable transporter 65 such as a robot (not shown) may be used to transport the clamped charge 62 to the forming tool 72. The forming tool 72 broadly comprises a pair of mandrels 80a, 80b slideable on a tool base 74. The charge 62 is held between the mandrels 80a, 80b during the forming process,

described in more detail below, while the charge is formed onto the mandrel 80a, 80b.

FIGS. 3-12 illustrates additional details of the assembly 5 tool 38 as well as sequential steps for aligning and assembling the components 54, 56, 58, 60 (FIG. 12) the charge 62. Referring particularly to FIGS. 3 and 4, the assembly tool 38 comprises a vacuum table 40 having a substantially flat charge supporting surface 44, which includes a plurality 10 of generally parallel, transversely extending slots 42. A plurality of double acting cylinders 50 are mounted on the table 40 and respectively include axially extendable, elongate plungers 52 disposed above the vacuum table surface 44 which act as blade depth spacers. In other embodiments (not shown), 15 plungers 52 may be provided both above and below the table surface 44. The cylinders 50 may be air/gas, hydraulically or electrically actuated. An alignment fence 48 having a desired contour or changing radius  $R_1$  substantially corresponding to the radius  $R_1$  shown in FIG. 1, is secured to the table surface 20 44 by fasteners 55. In other embodiments, the contour  $R_1$  of the fence 48 may be changeable though the use of numeric control devices, pins, etc.

As will be discussed below in more detail, the assembly 25 tool 38 functions to pre-align the components 54, 56, 58, 60 (FIGS. 12) of a charge 62 (FIG. 2), sometimes also referred to

herein as a fiber preform assembly, such that the components 54, 56, 58, 60 of the charge 62 are aligned relative to each other, and are also aligned along the contour  $R_1$  of the alignment fence 48. As used herein, the term "charge" is 5 intended to include both fiber preforms or parts that may be dry or partially infused, and prepregs. In the illustrated embodiments discussed below, the charge 62 comprises a dry fiber preform 58 (FIG. 7), however, principals of the disclosed method and apparatus may be employed to fabricate 10 composites structures using prepregs.

Referring to FIG. 5, in use, a charge 62 (FIG. 2) is stacked up by first placing a resin distribution media 54 on the table surface 44, aligned along the contoured fence 48. 15 Next, as shown in FIG. 6, a ply of a permeable parting film 56 is placed on the distribution media 54, also aligned along the contour of the fence 48.

Referring to FIG. 7, next, a fiber preform 58 which may 20 comprise one or more tubular or sock-like braided fiber preform 58a, 58b (see FIG. 16), is placed over the permeable parting film 56 shown in FIG. 6, also aligned along the contoured fence 48. Then, as shown in FIG. 8, a second ply of 25 a permeable parting film 60 is placed on the fiber preform 58 and is aligned along the fence 48, thereby forming a complete charge or preform assembly 62 comprising two plies of

permeable parting film 56, 60, resin distribution media 54 and the braided fiber preform 58 (see FIG. 12). The use of a braided fiber preform 58 may allow automated fabrication of an engineered preform that allows compound curvature of the 5 stringer 30 and facilitates layup. The braided fiber preform 58 may comprise crimped or non-crimped fibers, and may comprise a biaxial braid of three or more fibers or a triaxial braid in order to provide the stringer 30 (FIG. 1) with additional strength. Also, fiber preforms fabricated by 10 processes other than braiding may be possible.

The charge 62 having been sequentially formed and pre-aligned along the fence 48, and the blade height "H" shown in FIG. 1 having been pre-established by the axial positions of 15 the plungers 64 (FIG. 8), a plurality of clamps 68 (FIG. 8), or other suitable clamping mechanisms, are placed in and guided along the slots 42 in the table 40 until they are brought into abutment with the plungers 64, as best seen in FIGS. 9 and 12.

20

Each of the clamps 68 may be a scissor-action or other type of "C" clamp, such as that shown in FIGS. 12, 14 and 16, having a pair of opposing jaws 67 with lateral flanges 68a, 68b respectively. As shown in FIG. 12, one of the jaws 67 of 25 each clamp 68 is received within and slideable along one of the slots 42 beneath the charge 62, while the other jaw 67 of

the clamp 68 extends over the top of the charge 62. The clamps 68 are positioned around the charge 62 and passed through the slots 42 in the table 40 shown in FIGS. 4-12 until the lateral flange 68a of one of the jaws 67 (see FIG. 12) 5 engages the end of the plunger 64 above the charge 62. In alternate embodiments (not shown in the Figures) plungers 64 may be provided both above and below the table surface 44 (FIG. 4), in which case both lateral flanges 68a, 68b will engage and stop against one of the plungers 64. The plungers 10 64 therefore act as stops which determine the position of the clamps 68 on the charge 62, and particularly the location of the lateral flanges 68a, 68b, on the charge 62. Effectively, the blade height "H" established by the axial positions of the plungers 64 is transferred to the clamps 68, since the lateral 15 flanges 68a, 68b on the jaws 67 of the clamps 68 abut the plungers 64.

In an alternate embodiment shown in FIG. 10, the blade height "H" may be established by placing a continuous block or 20 plate 66 on each side of the charge 62 shown in FIG. 12. The clamps 68 (FIGS. 9 and 12) are then installed on the charge 62, abutting the plate 66 to establish the blade height "H". Thus, the blade height "H" may be established by using discrete, spaced apart elements (e.g. plungers 64), or by a 25 continuous element (e.g. the plate 66).

In an optional embodiment, shown in FIG. 11, a magnetic transfer bar 70 may be attached to the clamps 68 in order to hold and stabilize the clamped charge 62 while it is being transferred to the forming tool 72 shown in FIGS. 11-20 by the 5 transporter 65 (FIG. 2). A variety of other means of stabilizing the clamps 68 and thus the preform assembly 62 during transfer to the forming tool 72 may be employed, such as without limitation, grips, plates, ball-lock pins, rods and fixtures (all not shown).

10

Referring now to FIGS. 13 and 14, in one embodiment, the forming tool 72 may be employed to form, infuse and cure the preform assembly 62 (FIG. 12) described above. Infusion may be performed using a controlled atmospheric pressure resin 15 infusion process in order to achieve cost effective manufacture of the stringers 30. One such suitable infusion process is described in US Patent No. 7,334,782 issued February 26, 2008, the entire disclosure of which is incorporated by reference herein, however, other infusion 20 processes may be possible.

The forming tool 72 broadly comprises a pair of mandrels 80a, 80b at least one of which is slideable on a low friction slip plate 82 (FIG. 14) that is supported on a tool base 74. 25 The tool base 74 may be contoured along its length to substantially match the first contour  $R_1$  (FIG. 1) of the

stringer 30. The mandrels 80a, 80b have opposing tool faces 80c that are contoured along their lengths to substantially match the second contour  $R_2$  of the stinger (FIG. 1). A pair of curve blocks 76, 78 are mounted on opposite sides of and 5 sealed to the tool base 74 having a curvature generally matching the first contour  $R_1$  (FIG. 1) of the stringer 30. Alternatively, curve blocks 76, 78 and tool base 74 may be one contiguous piece either by bonding, welding or machining a pocket from a single block of material. An inflatable bladder 10 90 is sandwiched between curve blocks 76 and mandrel 80a.

In one embodiment, the mandrels 80a, 80b may each comprise a single piece, while in other embodiments, they may each be segmented along their length (not shown). The 15 opposing tool faces 80c of the mandrels 80a, 80b are laterally spaced apart from each other to form a tapered slot 84 therebetween. Each of the mandrels 80a, 80b further includes an upper, generally flat tool surface 86. Mandrel 80b is provided with a longitudinally extending resin inlet groove 92 20 therein for purposes discussed later. The tool base 74 may include a pneumatic fitting 94 adapted to be coupled with an outer bag air regulator (not shown).

Referring particularly to FIG. 13, the end 107 of the 25 tool 72 includes an internal pneumatic passageway 96 that couples the inflatable bladder 90 through a valve 97 to a

vacuum 98, vent 100 and compressed air 102 for controlling inflation and deflation of the bladder 90. The location of later discussed inner and outer bag seals are respectively indicated at 104 and 106.

5

FIG. 15 illustrates the forming tool 72 after an inner IML (inner mold line) bag 108, also referred to herein as a first bag 108, has been placed over and sealed to the tool 72 by an inner bag seals 104. The inner first bag 108 is wider than the tool 72 such that a portion 109 of the bag 108 drapes down over an edge 111 of the forming 72. As will be discussed later, inner bag portion 109 may be subsequently be folded back over the pre-form assembly 62 (not shown in FIG. 15) and sealed to the tool 72. Following placement on the tool 72, a slight vacuum may be applied through fitting 94 (FIG. 22) to the inner bag 108 in order to draw it down against the tool block surfaces 86 and into the slot 84 between the mandrels 80a, 80b. For clarity of the description below, not all areas of the inner first bag 108 are shown in FIGS. 14-19.

20

Following installation of the inner first vacuum bag 108, the pre-aligned preform assembly 62 is transferred from the assembly tool 38 (FIGS. 2-12) to the forming tool 72 by the transporter 65 (see FIG. 2). Referring to FIG. 16, with the bladder 90 deflated and the mandrels 80a, 80b spread to form the open slot 84, the clamped preform assembly 62 is inserted

into the slot 84 between the opposing mandrel surfaces 80c. For sake of clarity, the parting films 56, 60 are not shown in either FIG. 16, or 17 discussed below. The position of the clamps 68 on the preform assembly 62, and particularly the 5 location of the flanges 68a, 68b, define a web portion 62a corresponding to the web portion 32 (FIG. 1) of the stinger 30, and a flange portion 62b corresponding to the flange portion 34 of the stinger 30. The flanges 68a, 68b are brought into engagement with the upper mandrel surfaces 86 as 10 the preform assembly 62 is inserted into the slot 84, thereby establishing the web height "H" shown in FIG. 1.

FIG. 17 illustrates the next step in the assembly process, in which the bladder 90 is inflated to apply a force 15 in the direction shown by arrow 110, causing the mandrel 80a to slide toward the mandrel 80b, thereby clamping the web portion 62a of the preform assembly 62 between the two mandrels 80a and 80b, while the flange portion 62b of the preform assembly 62 remains held by the clamps 68. It should 20 be noted here that while a bladder 90 has been shown in the illustrated embodiment, other means of drawing the mandrels 80a, 80b together to clamp the assembly 62 may be possible, including but not limited to motors, screws, mechanical mechanisms (all not shown).

Referring now to FIG. 18, the next step in the assembly process involves removal of the clamps 68 from the preform assembly 62, after the web portion 62a of the assembly 62 has been clamped between the mandrels 80a, 80b, leaving the flange 5 portion 62b of the assembly 62 exposed above the upper mandrel surfaces 86. A resin inlet spiral wrap 112 is then placed in the groove 92 and is coupled with a suitable source of resin (not shown).

10 Referring to FIG. 19, the next step in the assembly process involves folding the flange portion 62b of the preform assembly 62 in the directions shown by the arrows 116, down onto the upper mandrel surfaces 86. This folding process also results in folding of the resin distribution media 54 over and 15 into contact with the resin inlet spiral wrap 112 so that resin introduced through the spiral wrap 112 flows into the resin distribution media 54 during the subsequent infusion process. During this folding process, any fiber angle distortion of the fiber preform 58 is minimized or 20 substantially eliminated as a result of the web portion 62a having been previously clamped and held in place while the flange portion 62b is being formed into flanges 114.

Clamping of the preform assembly 62 also assists in 25 debulking the web portion 62a of the preform 58. Folding of the flanges 114 onto the upper mandrel surfaces 86 may result

in a radius gap 118 being formed at the intersection of flanges 114 and web portion 62a. In this event, as shown in FIG. 20, a suitable radius gap filler 120 may be inserted into the gap 118. In the case of an "L" shaped part, a non-stick 5 re-usable radius filler may be used.

Attention is now directed to FIG. 21 which illustrates the forming tool 72 at a later, optional stage of the assembly process in those applications where the stringer 30 (FIG. 1) 10 includes a cap 124 used to cover and reinforce the flange 34 (FIG. 1). In this stage, a fiber cap preform 124, a permeable parting film (not shown), a permeable caul plate 126 and resin distribution media 128 are sequentially stacked on top of the flanges 114. Resin exit tubes 122 are placed along the edge 15 of the flange 114 and at the ends of the web portion 62a of the preform assembly 62. In lieu of placing two end exit tubes for the web portion of 62a, a continuous resin exit tube (not shown) may be placed into the inner bag prior to 20 insertion of the preform charge. The exit tubes 122 allow complete evacuation of air and gases as well as excess resin to bleed away from the infused preform 58, so that substantially uniform pressure is applied to the preform 58 during curing.

25 Attention is now directed to FIG. 22 which illustrates the forming tool 72 in a further stage of the assembly

process. The bag portion 109 has been folded back over the tool and sealed by the seals 104. Then, an outer second vacuum bag 130 is placed over the tool 72 covering the inner bag 108 and the preform assembly 62. The outer second vacuum bag 130 is then sealed to the forming tool 72 including the upper surfaces 86 of the curved blocks 76, 78 by outer bag seal 106. Fitting 94 may then be coupled with a suitable outer bag regulator (not shown) which regulates the vacuum applied to the outer bag 130. Air is then evacuated from the inner and outer bags 108, 130 substantially simultaneously. In one exemplary embodiment, the inner bag 108 is drawn to a slightly higher vacuum than the outer bag 130. For example, and without limitation, in one application, the inner bag 108 may be drawn to a vacuum of approximately 30 Hg while the outer bag 130 is drawn to approximately 25 Hg.

Following forming and compaction, the pressure applied to the preform assembly 62 may be adjusted, as required. In one example, the cure pressure applied to the web portion 62a (FIG. 22) is established by the pressure applied to the mandrel 80a by the bladder 90. The cure pressure applied to the flanges 114 is established by the vacuum level in the inner bag 108 and the pressure holding the flanges 114 on the mandrel surfaces 86 established by the vacuum level in the outer bag 130. After curing, the outer bag 130 is removed, following which the bladder 90 is deflated. Deflation of the

bladder 90 allows the mandrels 80a, 80b to move apart, thereby unclamping the inner bag 108 and all of its contents, including the resin infused preform 58 which has become the cured stringer 30 and all associated disposable materials to 5 be removed from the forming tool 72.

Attention is now directed to FIG. 23 which illustrates a method of making a contoured composite part according to the disclosed embodiments previously discussed. Beginning at 134, 10 a charge which may comprise a fiber preform assembly 62 is stacked up and aligned, following which, at 136, the pre-aligned preform assembly 62 is placed in a forming tool 72. Next, at 138, the preform assembly 62 is infused with resin following which, at 140, the resin infused preform assembly 62 15 is cured.

FIG. 24 illustrates another embodiment of a method for making a composite structural member according to the disclosed embodiments. Beginning at 142, a resin distribution 20 media ply 54 is placed on an assembly tool 38 following which at 144, a first permeable parting film ply 56 is placed over the resin distribution media ply 54. At 146, a suitable braided fiber preform 58 is placed over the first permeable parting film 56 ply following which a second permeable parting 25 film ply 60 is placed over the preform 58, as shown at 148. At 150, one or more blade height spacers 64 or 66 are placed

on the charge, and at 152, the stacked assembly 62 is clamped together to maintain ply alignment. Next, at 156, the pre-aligned preform assembly 62 is transferred to a forming tool 72 where it is resin infused and cured.

5

FIG. 25 illustrates additional details of a method of making a contoured composite structural member 30 having a web 32 and at least one flange 34. Beginning at 158, an inner vacuum bag 108 is installed on a forming tool 72 following 10 which, at 162 a vacuum is applied to the inner bag 108 to draw it down onto the forming tool 72. At 161 an exit spiral wrap 122 is placed in the bottom of the vacuum bag groove. Next, at 162, a clamped preform assembly or charge 62 is loaded onto the forming tool 72, and at 164, a bladder 90 is inflated 15 which clamps and debulks the preform assembly 62. At 166, the assembly 62 is unclamped, and at 170, an inlet spiral wrap 112 is installed in an resin inlet groove 92 in the tool 72 as shown at 170.

20 Next, at 172, flanges 114 of the preform assembly 62 are folded into position, following which at 174, a radius filler 120 may be optionally installed into a gap 118 which may be present between the flanges 114. At 176, a cap charge 124 is applied over the preform flanges 114. At 178, a permeable 25 parting film 124 is applied over the cap charge 124 and at 180, a permeable caul plate 126 is applied over the permeable

parting film. At 182, a resin distribution media 128 applied over the caul plate 126, and at 184, resin exit tubes 122 are placed at each end of the flanges 114 and the web portion 62a of the charge 62. At 186, the inner bag 108 is sealed as 5 shown at 186. At 188, an outer bag 130 is installed over the preform charge assembly 62 and sealed to the assembly tool 72. At 190, air is evacuated from the inner and outer bags substantially simultaneously, and the preform charge assembly 62 is then infused with resin at 192. Next, at 194, the 10 infused charge 62 is cured and at 196 it is removed from the forming tool 72, trimmed as necessary and cut to the desired lengths.

It may be appreciated that since the inner bag 108 covers 15 the tool 72 during both the assembly and curing stages, the tool 72 may remain substantially free of resin or other residue and may require minimal or no cleaning in preparation for processing of the next part. It may also be appreciated that the inner bag 108 completely envelopes the part and 20 associated disposable materials, thus simplifying transfer to a non clean room type area for trim.

Referring next to FIGS. 26 and 27, embodiments of the disclosure may be used in the context of an aircraft 25 manufacturing and service method 200 as shown in FIG. 26 and an aircraft 202 as shown in FIG. 27. During pre-production,

exemplary method 200 may include specification and design 204 of the aircraft 202 and material procurement 98. During production, component and subassembly manufacturing 208 and system integration 210 of the aircraft 202 takes place.

5 During step 208, the disclosed method and apparatus may be employed to fabricate composite parts such as stiffeners which are then assembled at step 210. Thereafter, the aircraft 200 may go through certification and delivery 212 in order to be placed in service 214. While in service by a customer, the 10 aircraft 202 may be scheduled for routine maintenance and service 108 (which may also include modification, reconfiguration, refurbishment, and so on).

Each of the processes of method 200 may be performed or carried out by a system integrator, a third party, and/or an 15 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 20 suppliers; and an operator may be an airline, leasing company, military entity, service organization, and so on.

As shown in FIG. 27, the aircraft 202 produced by exemplary method 200 may include an airframe 218 with a plurality of systems 220 and an interior 222. The disclosed

method and apparatus may be employed to fabricate stiffeners such as stringers which form part of the airframe 110. Examples of high-level systems 220 include one or more of a propulsion system 224, an electrical system 226, a hydraulic system 228 and an environmental system 230. Any number of other systems may be included. Although an aerospace example is shown, the principles of the invention may be applied to other industries, such as the automotive industry.

The apparatus embodied herein may be employed during any one or more of the stages of the production and service method 200. For example, components or subassemblies corresponding to production process 208 may be fabricated or manufactured in a manner similar to components or subassemblies produced while the aircraft 202 is in service. Also, one or more apparatus embodiments may be utilized during the production stages 208 and 210, for example, by substantially expediting assembly of or reducing the cost of an aircraft 202. Similarly, one or more apparatus embodiments may be utilized while the aircraft 202 is in service, for example and without limitation, to maintenance and service 216.

Although the embodiments of this disclosure have been described with respect to certain exemplary embodiments, it is to be understood that the specific embodiments are for

purposes of illustration and not limitation, as other variations will occur to those of skill in the art.

**What is claimed is:**

1. A method of making a contoured composite part, the method comprising:

assembling a charge, including aligning a plurality of plies along a preselected contour;

placing a first vacuum bag over a forming tool before the charge is transferred to the forming tool and sealing the first vacuum bag to the forming tool;

transferring the charge to the forming tool;

forming the charge on the forming tool;

placing a second vacuum bag over the charge and sealing the second vacuum bag to the forming tool;

applying first and second vacuums respectively to the first and second vacuum bags;

infusing the charge with resin introduced into the first vacuum bag; and

curing the charge.

2. The method of claim 1, wherein:

assembling the charge includes placing at least one fiber preform on an assembly tool; and

aligning the plies includes using the assembly tool to align the fiber preform along the preselected contour.

3. The method of claim 2, wherein infusing the charge comprises infusing the fiber preform with resin after the charge has been transferred to the forming tool.

4. The method of any one of claims 1 to 3, further comprising:

maintaining the alignment of the plies in the charge by clamping the plies together after the charge has been assembled.

5. The method of any one of claims 1 to 3, further comprising:

clamping a first portion of the charge in the forming tool,

wherein forming the charge includes forming a second portion of the charge on the forming tool while the first portion is clamped.

6. An apparatus for making a composite structural member having at least one contour, the apparatus comprising:

an assembly tool for assembling a plurality of plies forming a charge;

a forming tool for forming the charge, the forming tool including a pair of relatively movable mandrels between which a first portion of the charge may be clamped;

a first vacuum bag adapted to cover the forming tool;

a second vacuum bag adapted to cover the charge clamped on the forming tool and hold at least a second portion of the charge against the forming tool;

first and second seals for sealing the first and second vacuum bags to the forming tool; and

a resin supply line for introducing resin into the first vacuum bag and infusing the charge.

7. The apparatus of claim 6, wherein the assembly tool includes:

a contoured alignment guide for aligning the plies along a first contour of the at least one contour; and

a clamping mechanism for clamping the aligned plies together.

8. The apparatus of claim 6 or 7, wherein:

the forming tool includes a substantially vacuum tight base having pass-throughs adapted to receive for vacuum, compressed air and resin lines;

the mandrels are relatively moveable on the base toward and away from each other; and

the mandrels include tool surfaces over which at least the second portion of the charge may be formed.

9. The apparatus of any one of claims 6 to 8, wherein the forming tool includes an inflatable bladder for applying clamping pressure to one of the mandrels.

10. The apparatus of any one of claims 6 to 9, wherein each of the mandrels includes a contoured clamping surface for forming a second contour of the at least one contour into the charge.

11. An apparatus for making a composite structural member having a web and having at least one contour, the apparatus comprising:

an assembly tool for assembling a plurality of plies forming a charge, wherein the assembly tool comprises:

an alignment guide having an adjustable contour against which the plies of the charge may be aligned and contoured; and

a spacer adapted to be placed on the charge and having a width substantially equal to a height of the web; and

a forming tool for forming the charge, the forming tool including a pair of relatively movable mandrels between which the charge may be clamped.

12. The apparatus of claim 11, wherein the assembly tool further includes:

a clamping mechanism for clamping the aligned plies together.

13. The apparatus of claim 11 or 12, wherein:

the forming tool includes a substantially vacuum tight base having pass-throughs adapted to receive for vacuum, compressed air and resin lines;

the mandrels are relatively moveable on the base toward and away from each other; and

the mandrels include tool surfaces over which at least a first portion of the charge may be formed.

14. The apparatus of any one of claims 11 to 13, wherein the forming tool includes an inflatable bladder for applying clamping pressure to one of the mandrels.

15. The apparatus of any one of claims 11 to 14, further comprising:

a first vacuum bag adapted to cover the forming tool;

a second vacuum bag adapted to cover the charge clamped on the forming tool and hold at least a second portion of the charge against the forming tool; and

a resin supply line for introducing resin into the first vacuum bag and infusing the charge.

16. The apparatus of any one of claims 11 to 15, wherein each of the mandrels includes a contoured clamping surface for forming a contour of the at least one contour into the charge.

17. An apparatus for making a composite member with a compound contour and having a web and at least one flange, the apparatus comprising:

an assembly tool for pre-aligning a multi-ply charge along a first contour of the compound contour, the assembly tool comprising:

a surface on which the charge may be assembled; an alignment guide having an adjustable contour against which the plies of the charge may be aligned and contoured;

a spacer adapted to be placed on the charge and having a width substantially equal to a height of the web; and

at least one clamp for clamping the aligned and contoured plies together with the spacer, and grooves to allow clamping access to both sides of the charge; and

a forming tool including a base and a pair of contoured mandrels on the base between which a web portion of the charge may be clamped and formed along a second contour of the compound contour.

18. The apparatus of claim 17, wherein at least one of the pair of contoured mandrels includes a tool surface onto which a flange portion of the charge may be formed.

19. An apparatus for making a compound contoured composite stringer for aircraft, the stringer having a web and a flange, the apparatus comprising:

an alignment and assembly tool, including:

a flat surface on which a flat charge may be placed;

an alignment fence having a first contour corresponding to one of the contours of the stringer and against which the charge may be aligned; and

a web height spacer for establishing the height of the web;

a plurality of clamps for clamping the charge and adapted to abut the web height spacer;

a forming and cure tool, including:

a tool base having a contour which largely matches the first contour of the alignment fence on the alignment and assembly tool, the tool base including an assembly of a base plate and spaced apart curved blocks; and

a pair of mandrels relatively slideable on the tool base toward and away from each other, the mandrels including a first set of opposing surfaces having a second contour corresponding to another one of the contours of the stringer and for clamping a web portion of the charge therebetween, the

mandrels further including a second set of surfaces onto which a flange portion of the charge may be formed;

a first bag covering the charge;

a second bag covering the charge and the first bag;

first and second seals for sealing the first and second bags to the forming and cure tool;

a resin infusion inlet for allowing resin to flow into the charge within the first bag; and

at least one resin outlet for allowing resin to escape from the charge.

20. A method of making a compound contoured composite blade stringer for aircraft, the method comprising:

placing a resin distribution media on an assembly tool;

placing a preform on the assembly tool covering the resin distribution media to form a preform charge;

aligning the resin distribution media and the preform charge relative to each other and along an alignment guide having a first contour;

placing a blade height spacer over the preform charge;

clamping a flange portion of the charge to maintain the alignment of the charge, including using the blade height spacer to control placement of clamps on the charge, to form a clamped charge;

installing an inner vacuum bag over a forming tool;

applying a first vacuum to a forming tool side of the inner vacuum bag and transferring the clamped charge to the forming tool;

clamping a web portion of the charge in the forming tool, including inflating a bladder and using the inflation of the bladder to move a pair of mandrels into clamping engagement with the charge;

removing the clamps from the flange portion of the charge while the web portion of the charge is clamped between the mandrels;

forming a formed charge including a pair of stringer flanges by folding the flange portion of the charge down onto the mandrels;

folding the inner vacuum bag back over the formed charge; placing an outer vacuum bag over the inner vacuum bag covering the formed charge;

sealing the inner and outer vacuum bags;

applying second and third vacuums respectively to the inner vacuum bag and the outer vacuum bag;

infusing the preform with resin by introducing resin into the inner vacuum bag to form a resin infused fiber preform;

curing the resin infused fiber preform on the forming tool to form a cured stringer; and

removing the cured stringer from the forming tool following curing.

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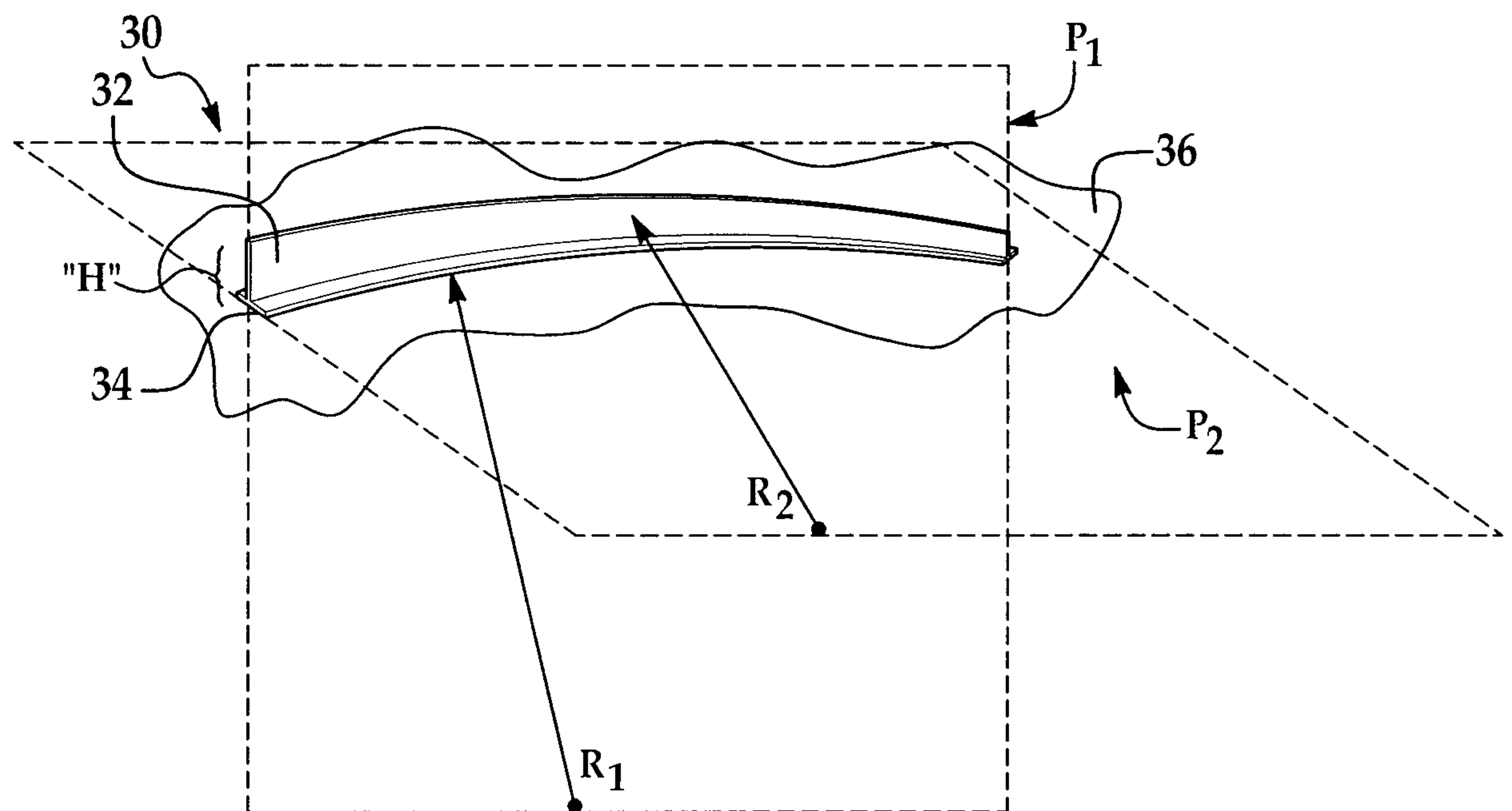


FIG. 1

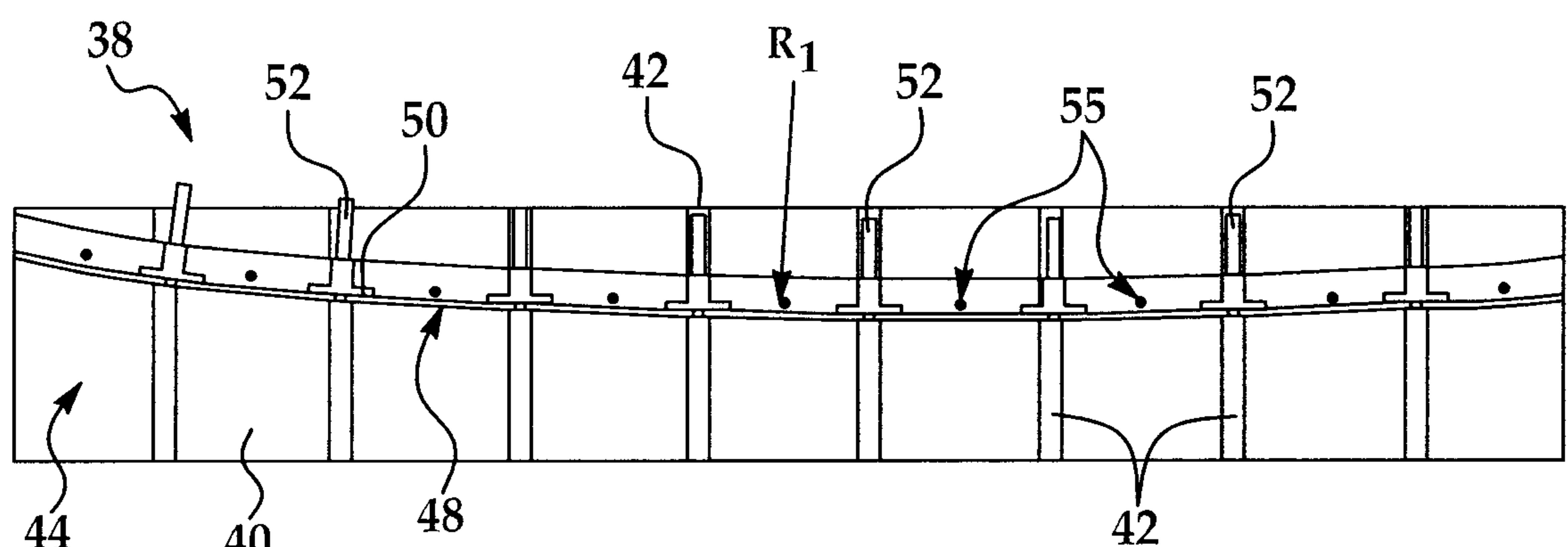


FIG. 3

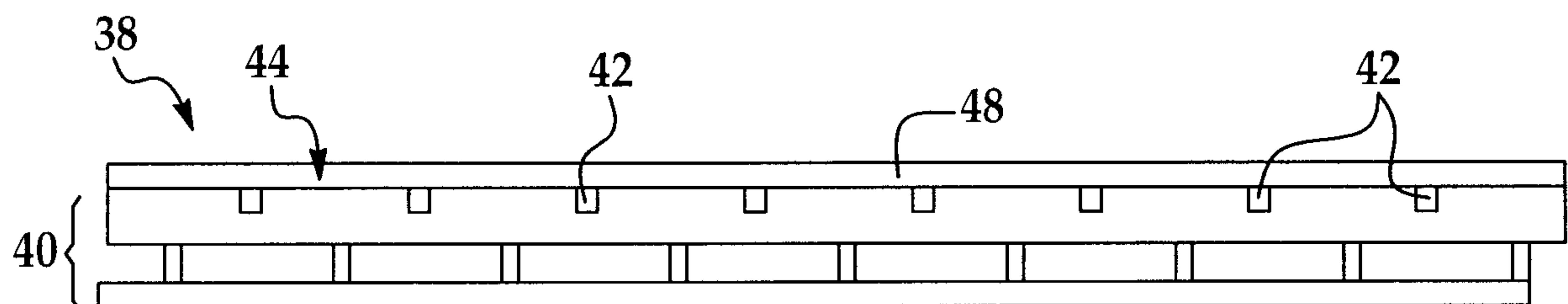


FIG. 4

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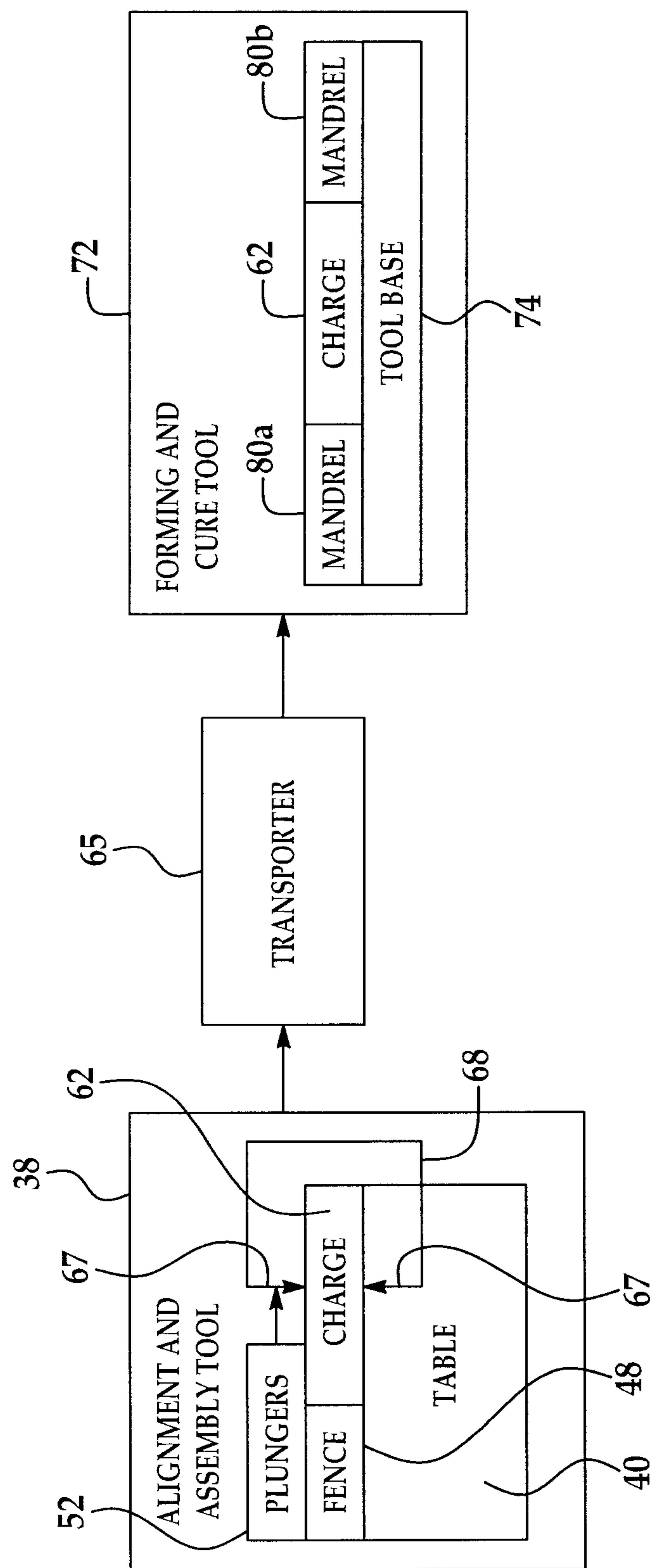


FIG. 2

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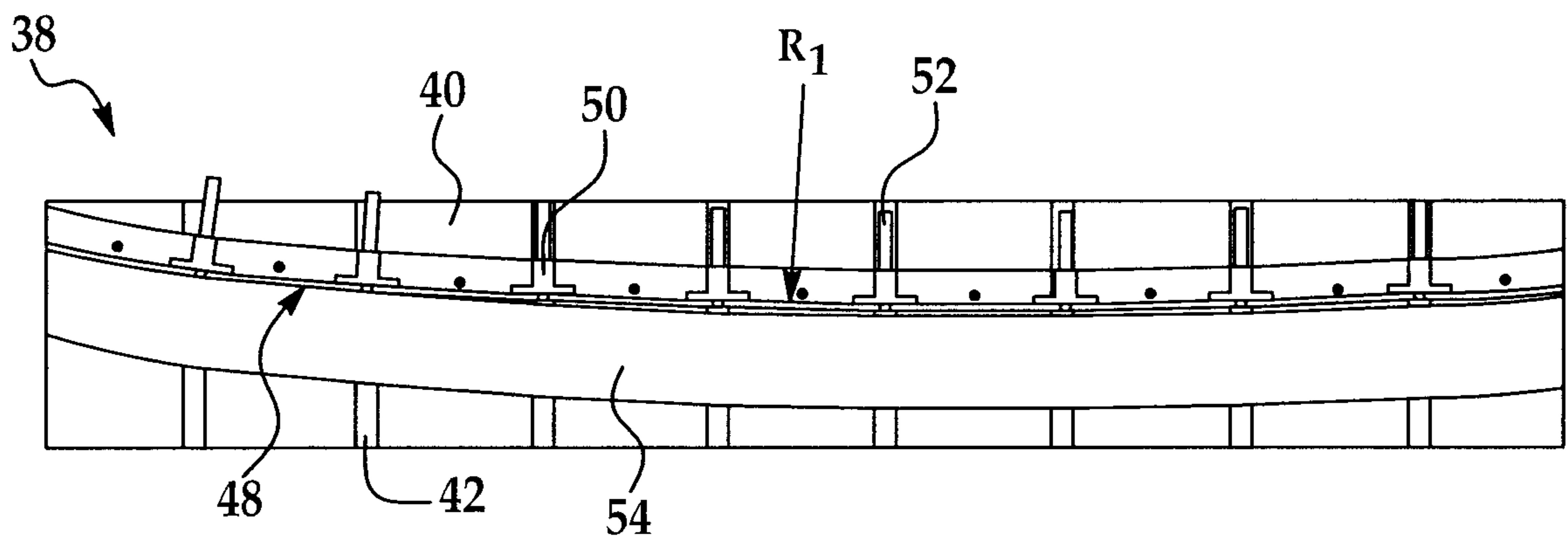


FIG. 5

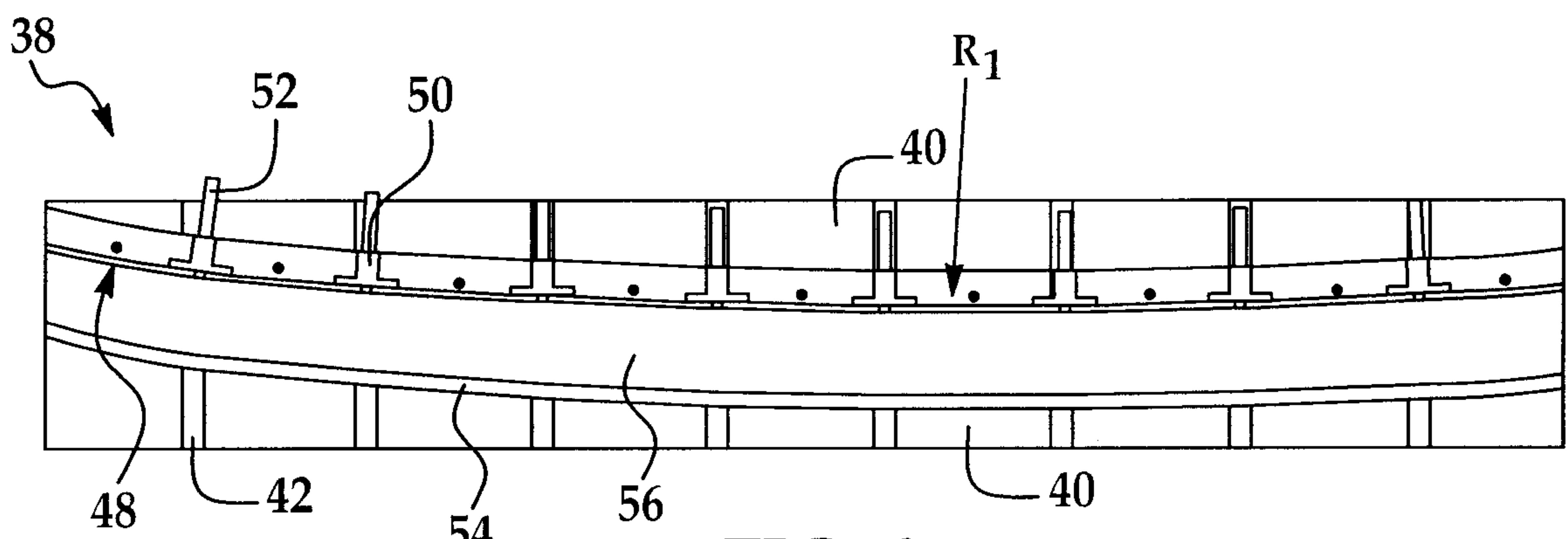


FIG. 6

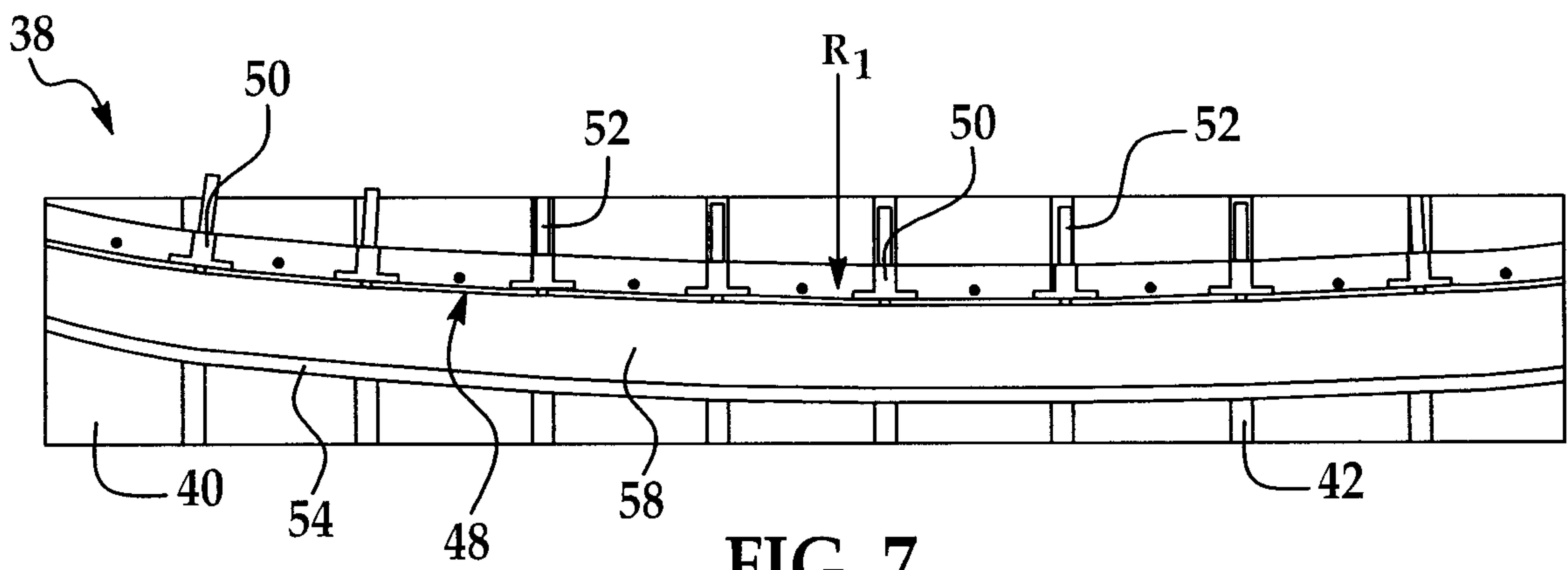


FIG. 7

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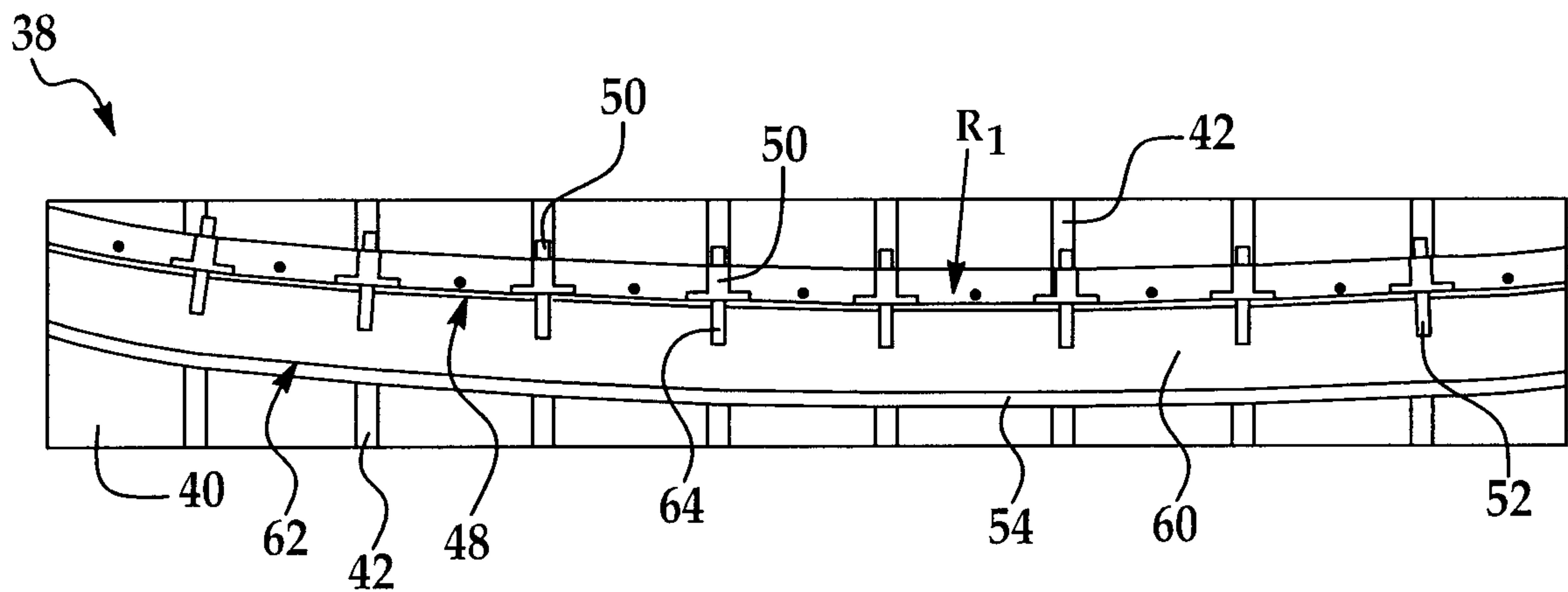


FIG. 8

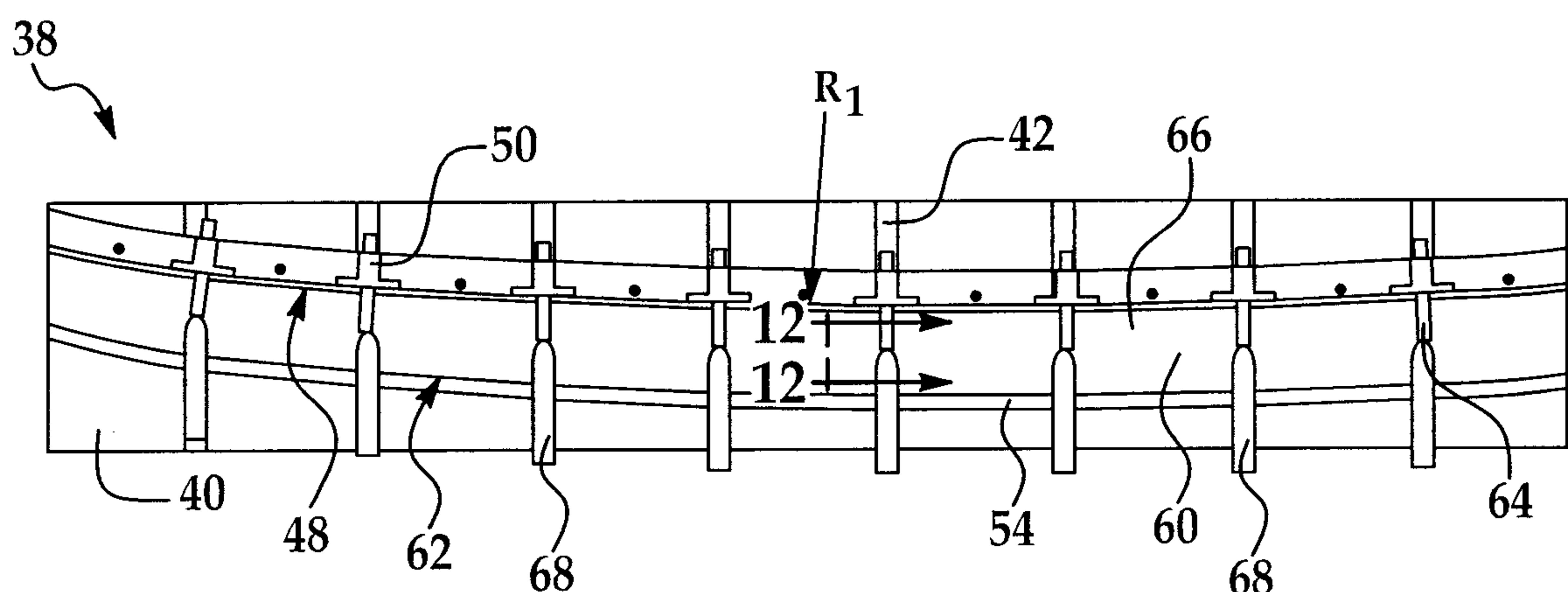


FIG. 9

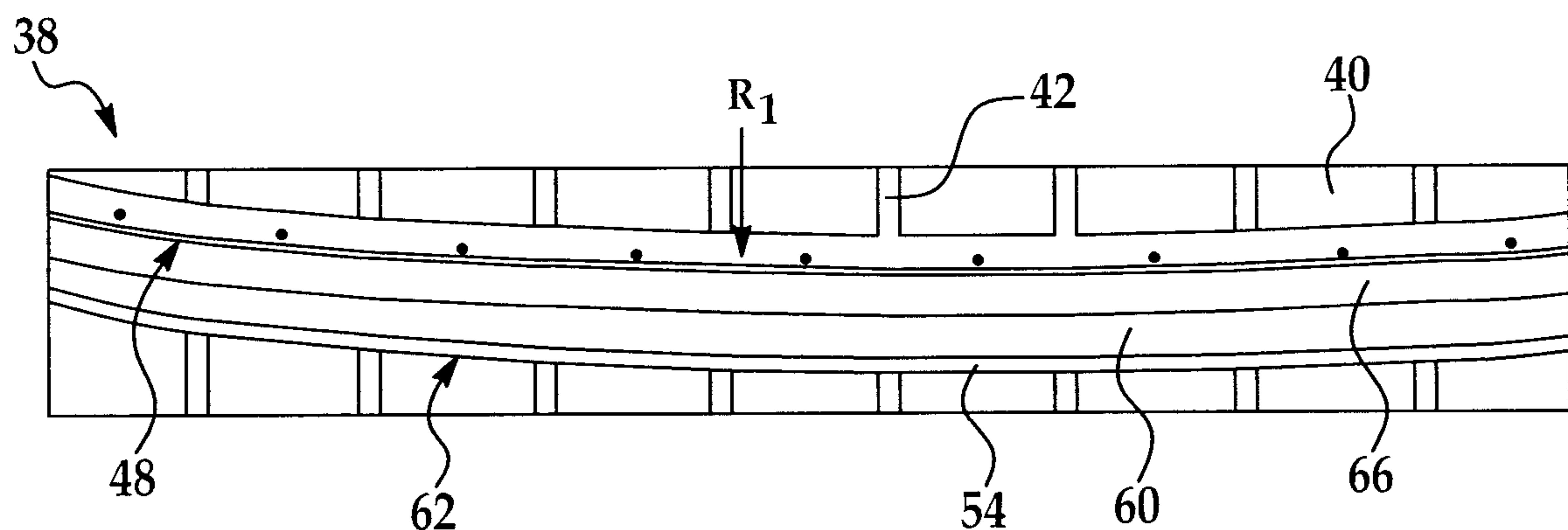


FIG. 10

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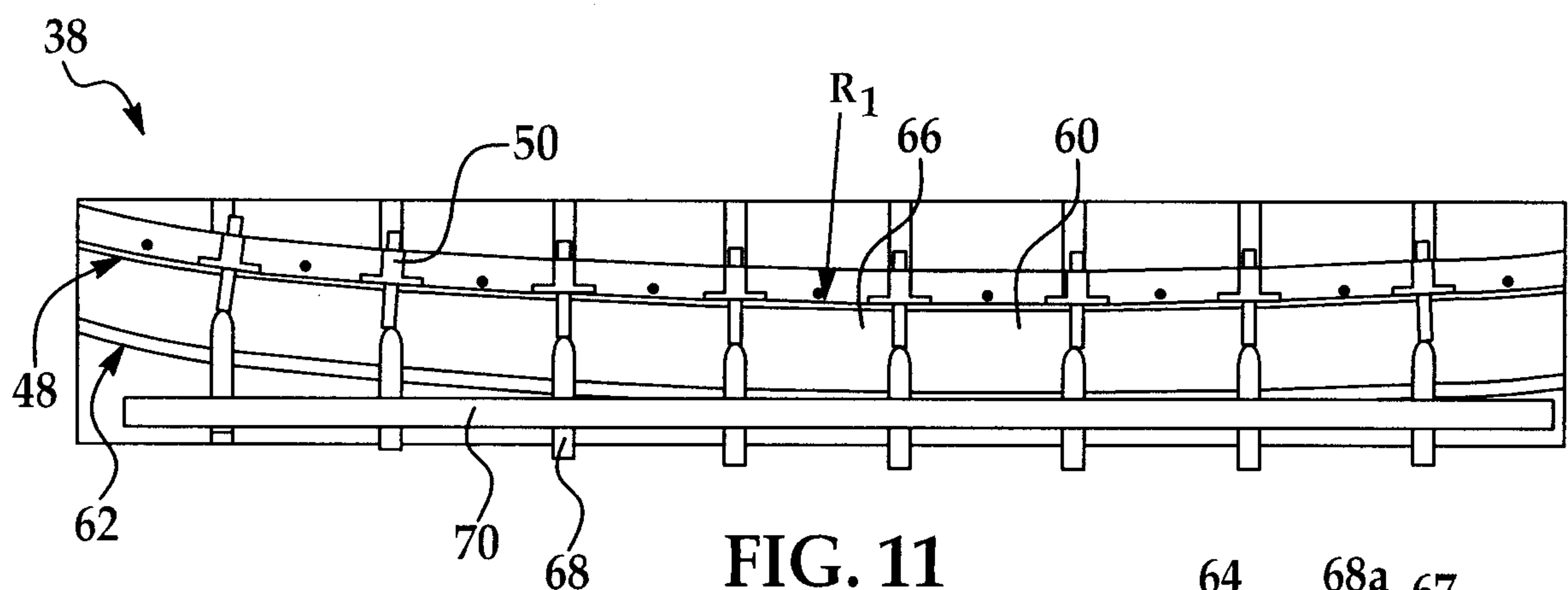


FIG. 11

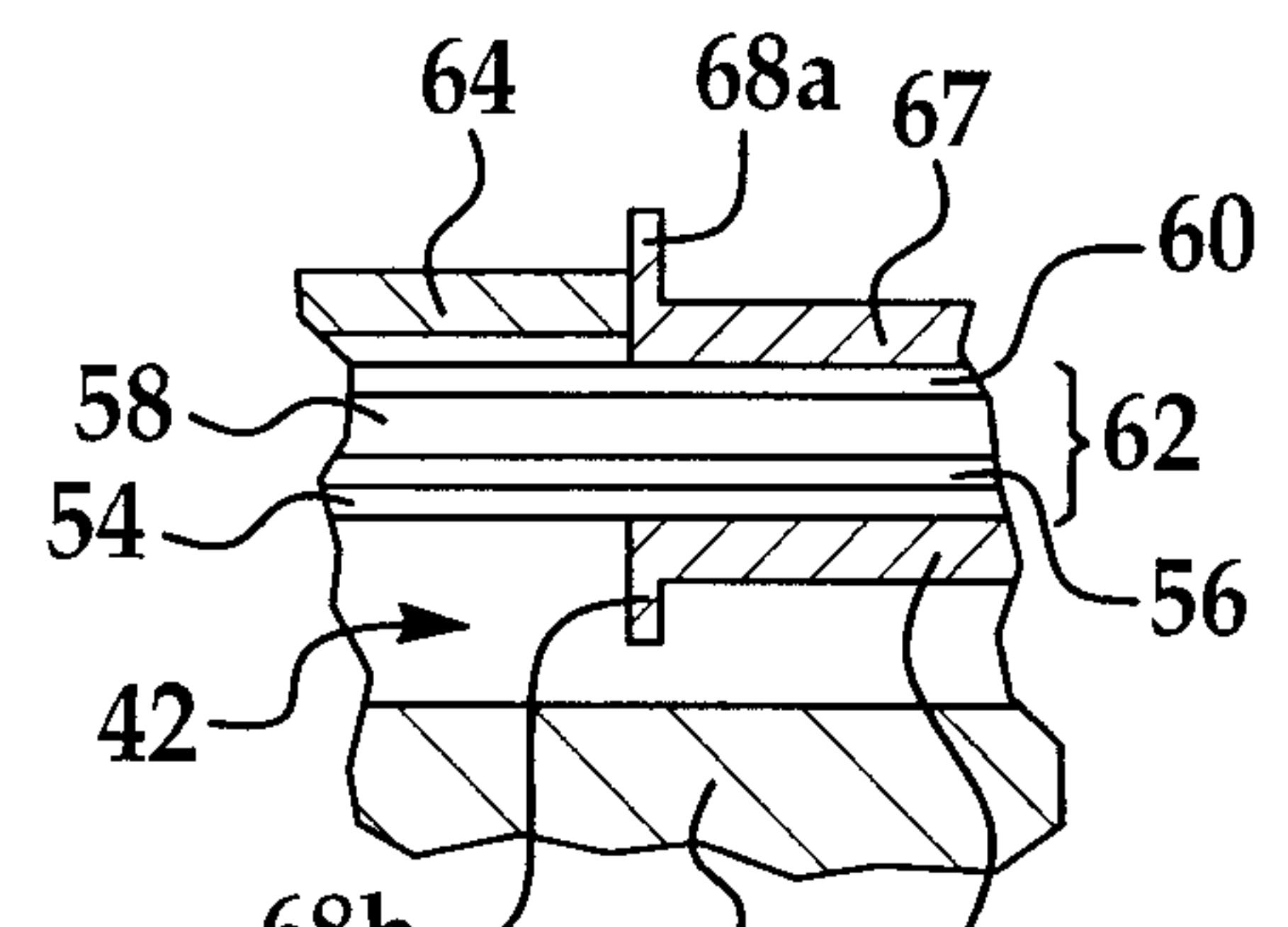


FIG. 12

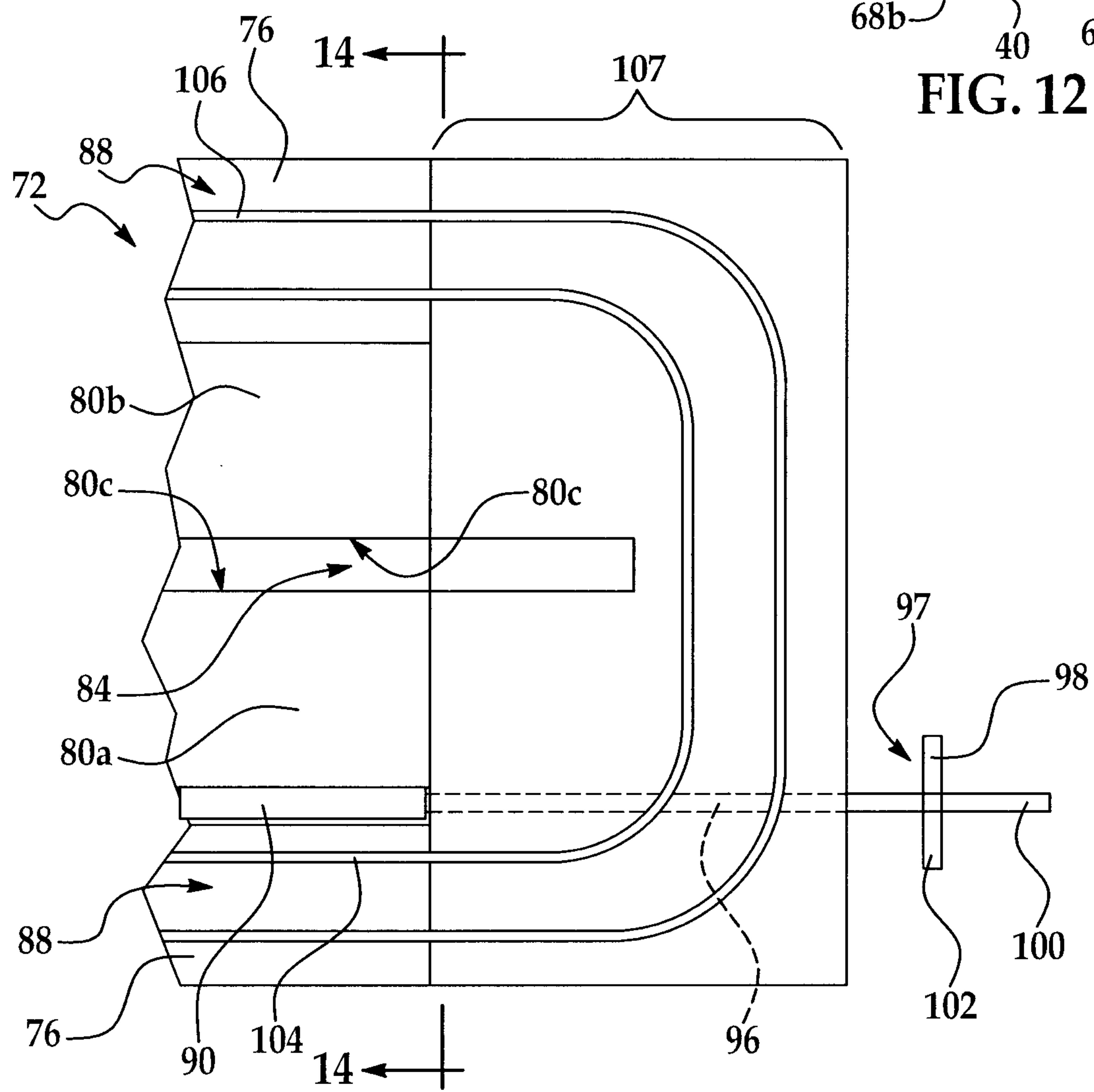


FIG. 13

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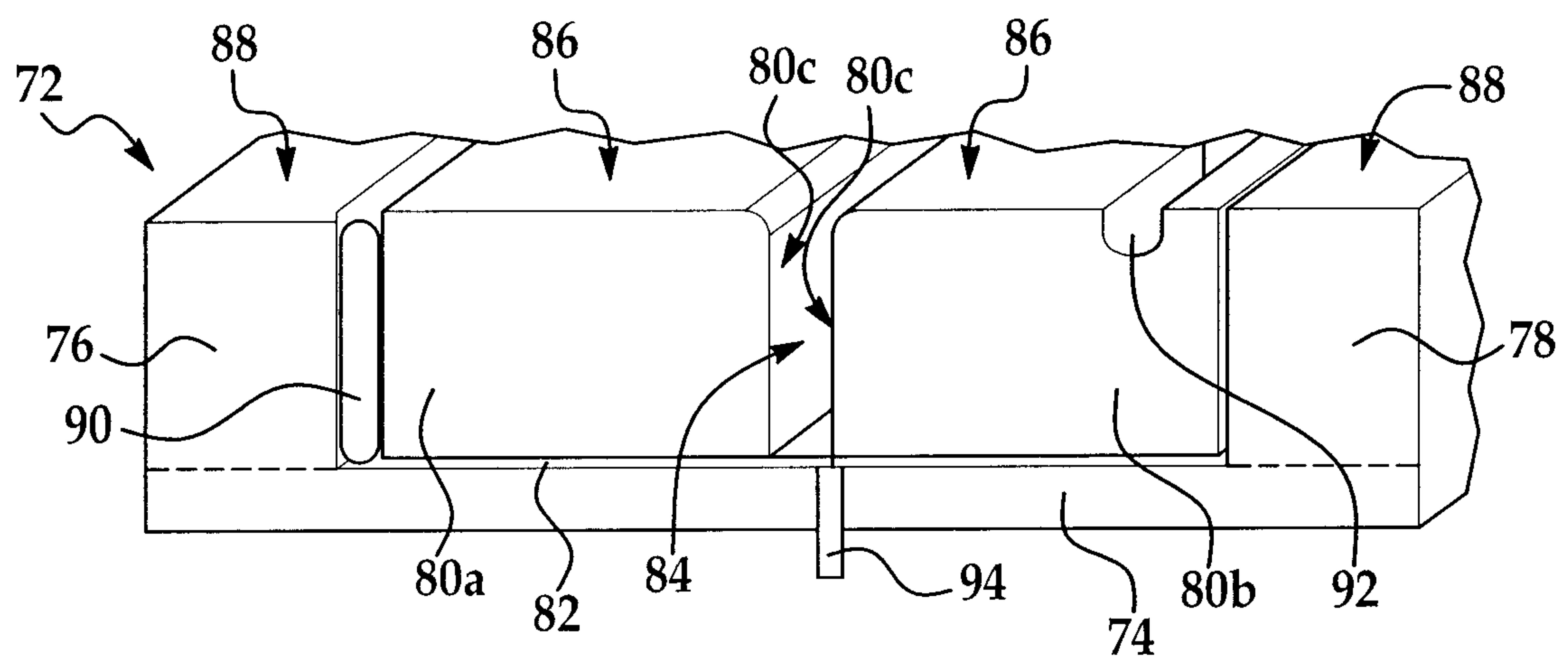


FIG. 14

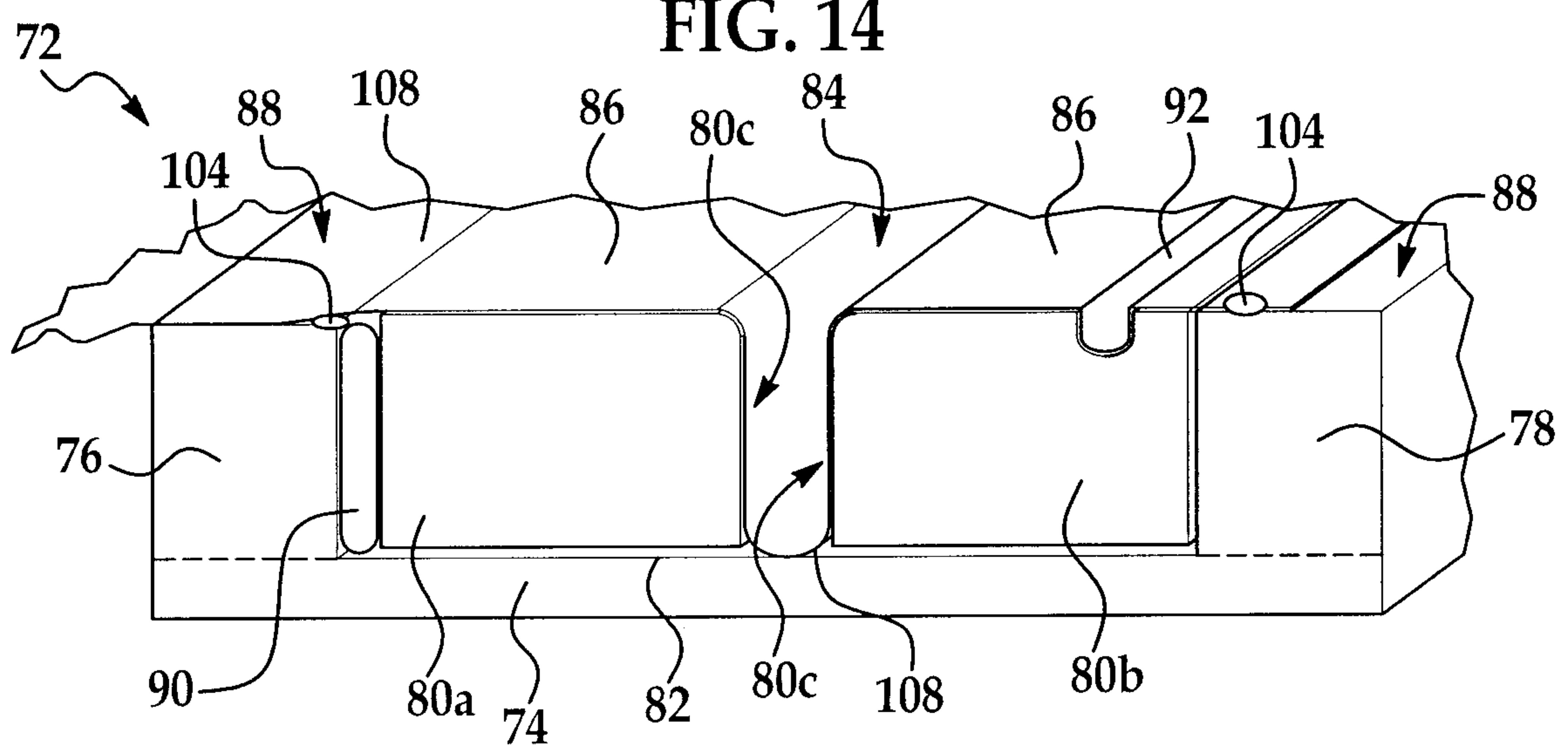


FIG. 15

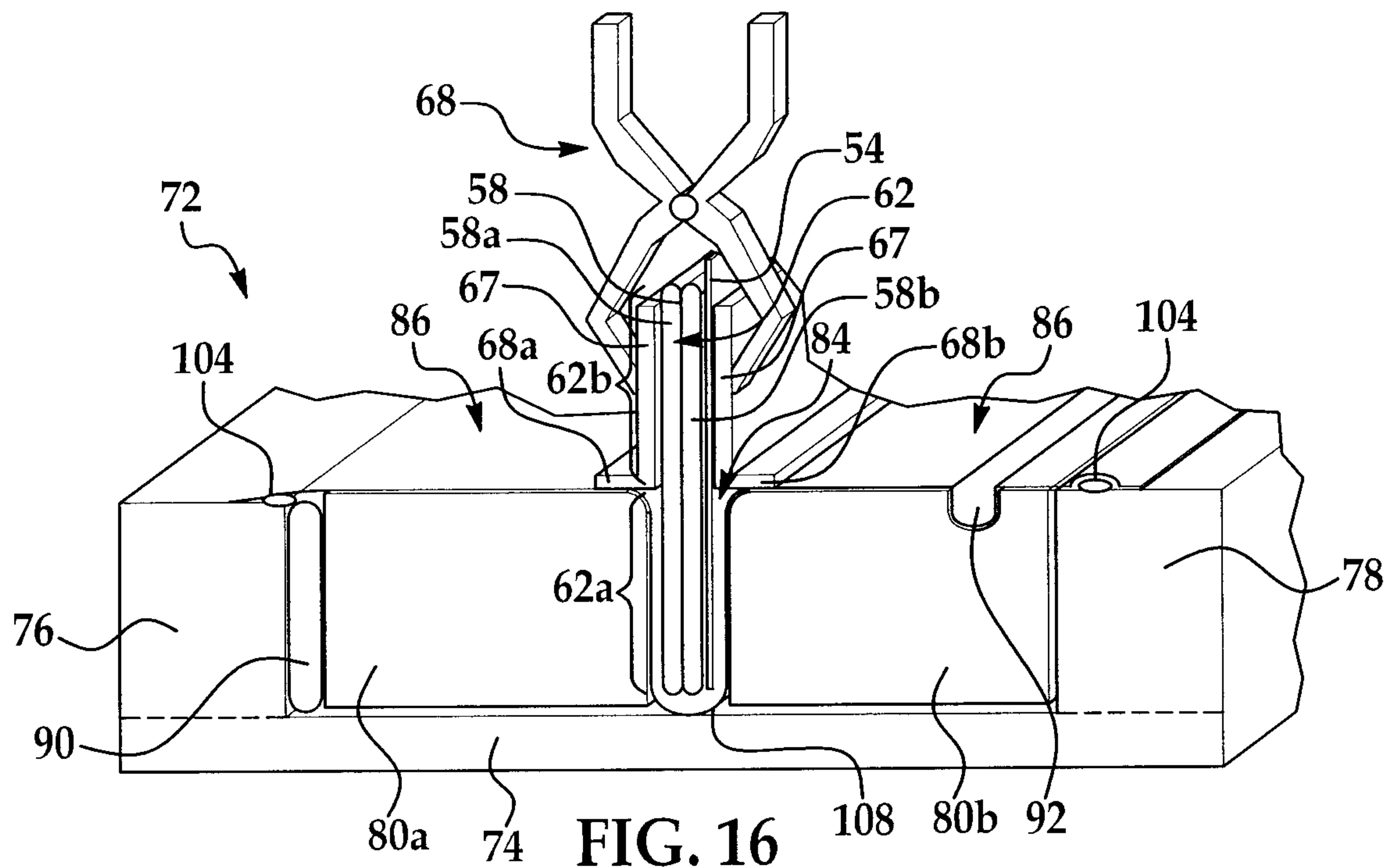


FIG. 16

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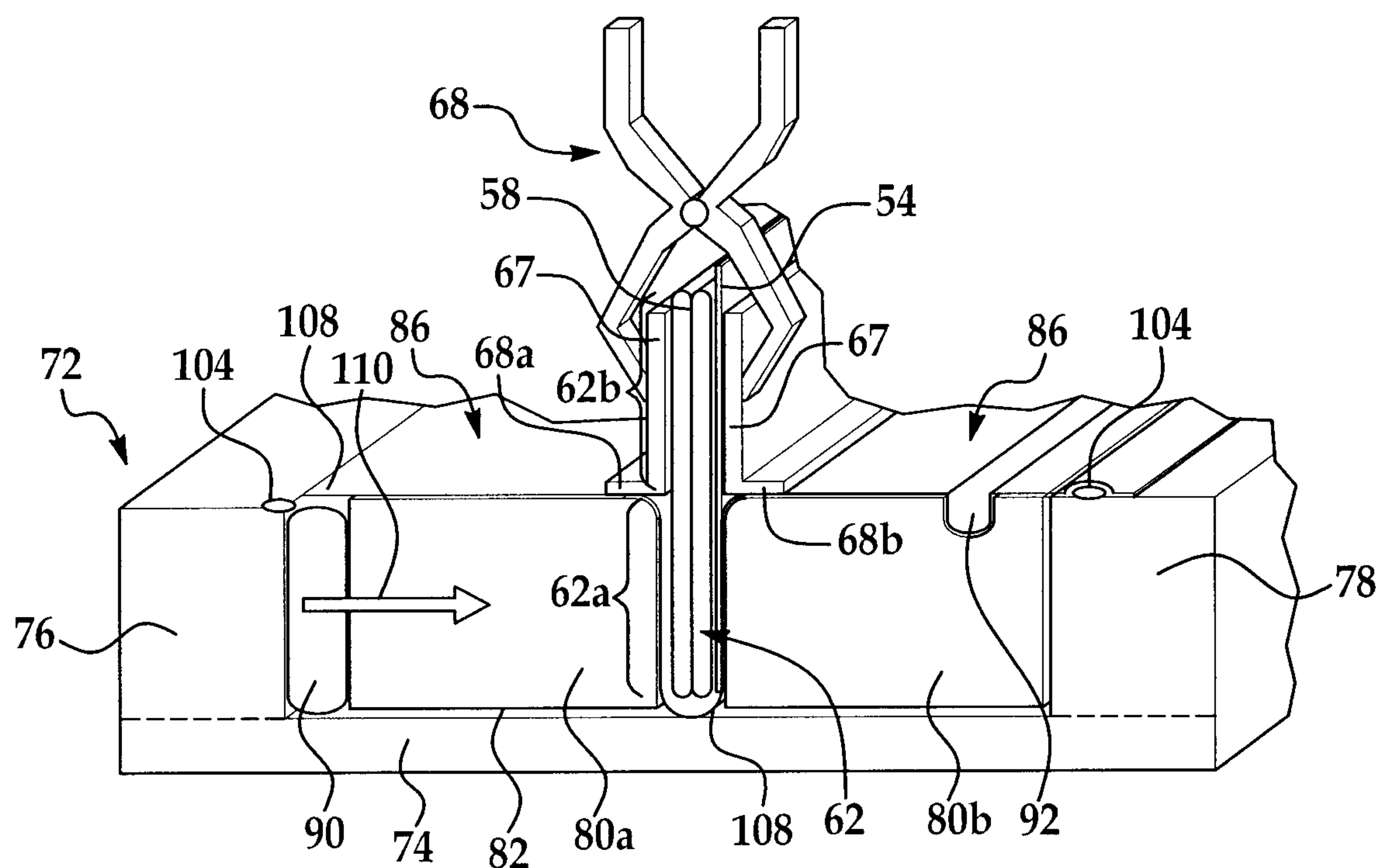


FIG. 17

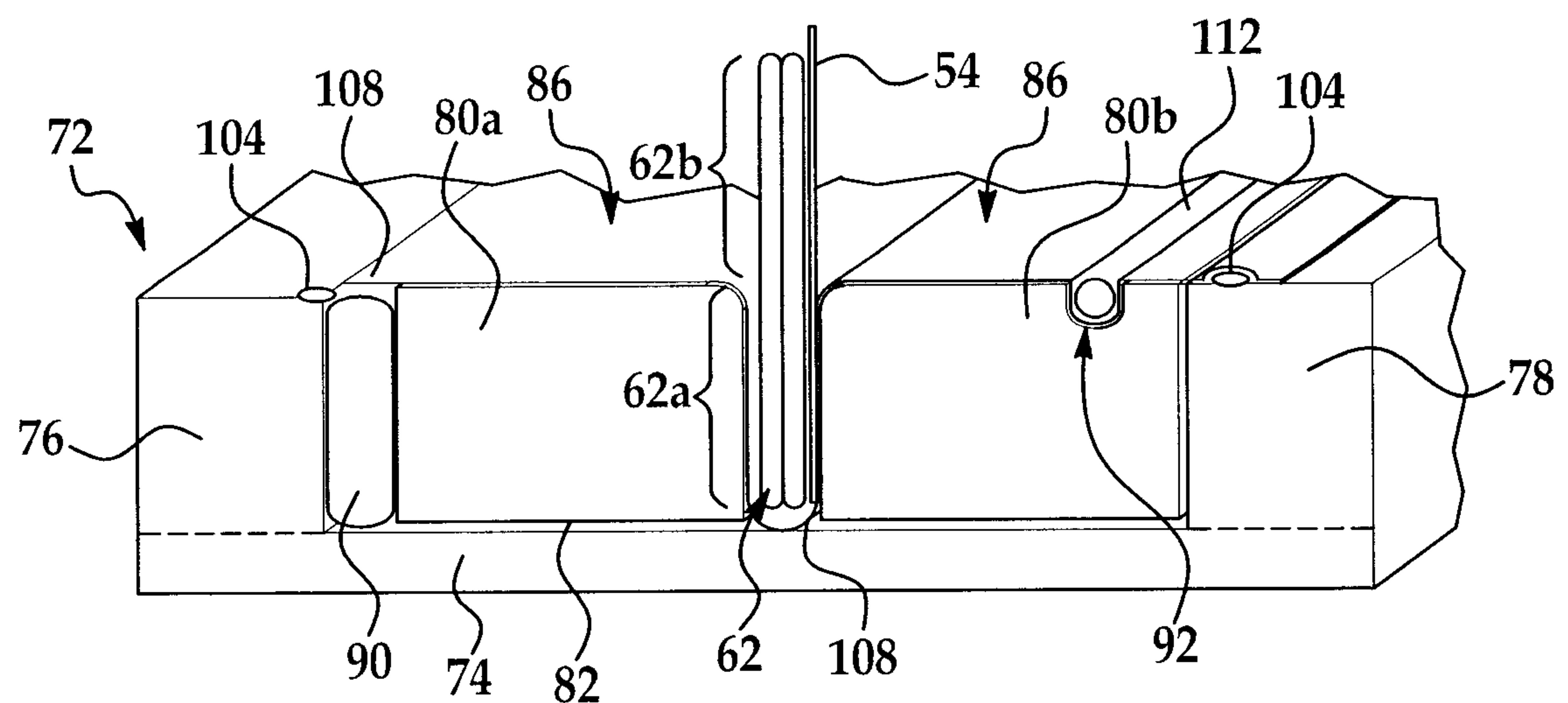


FIG. 18

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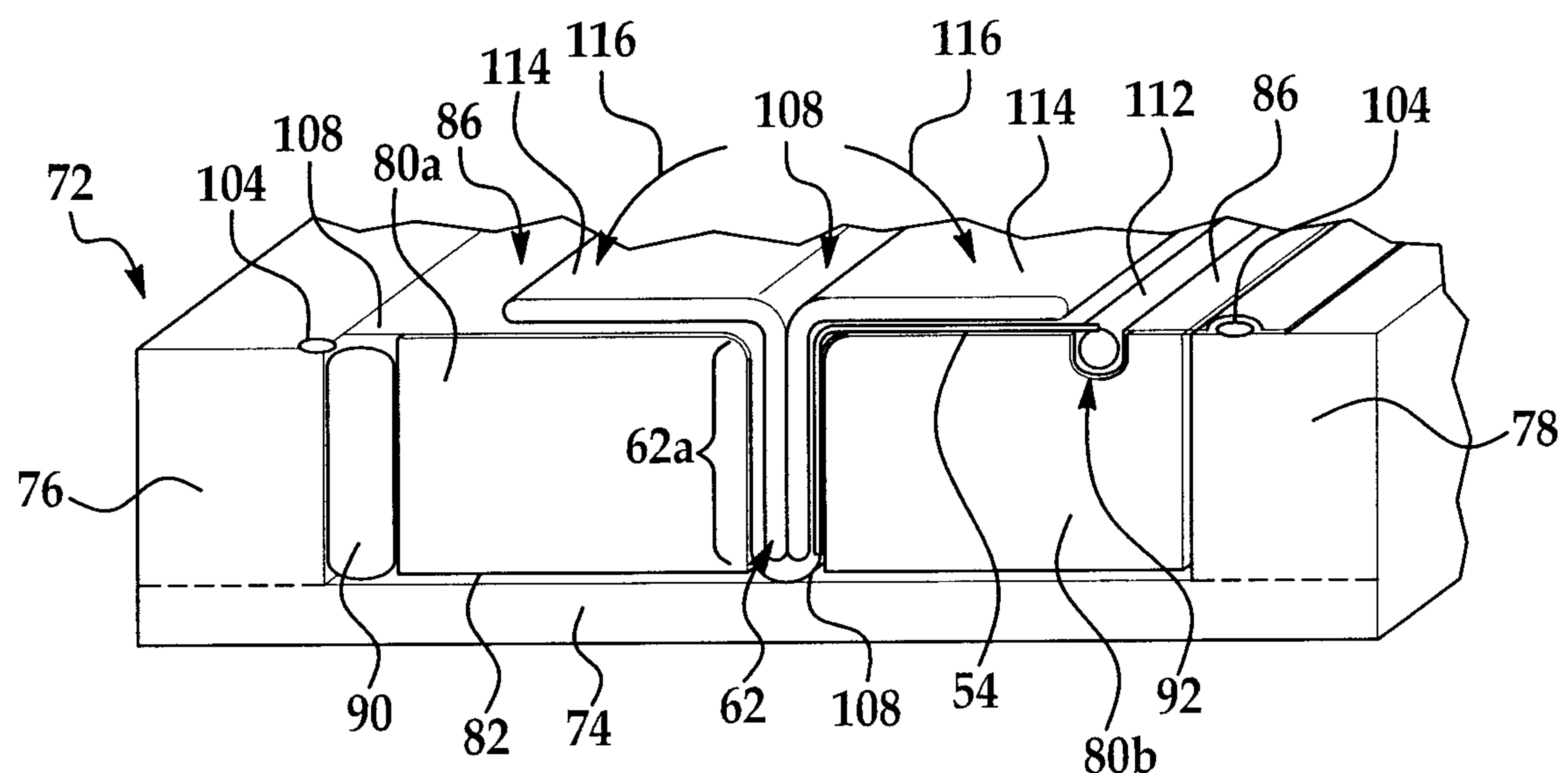


FIG. 19

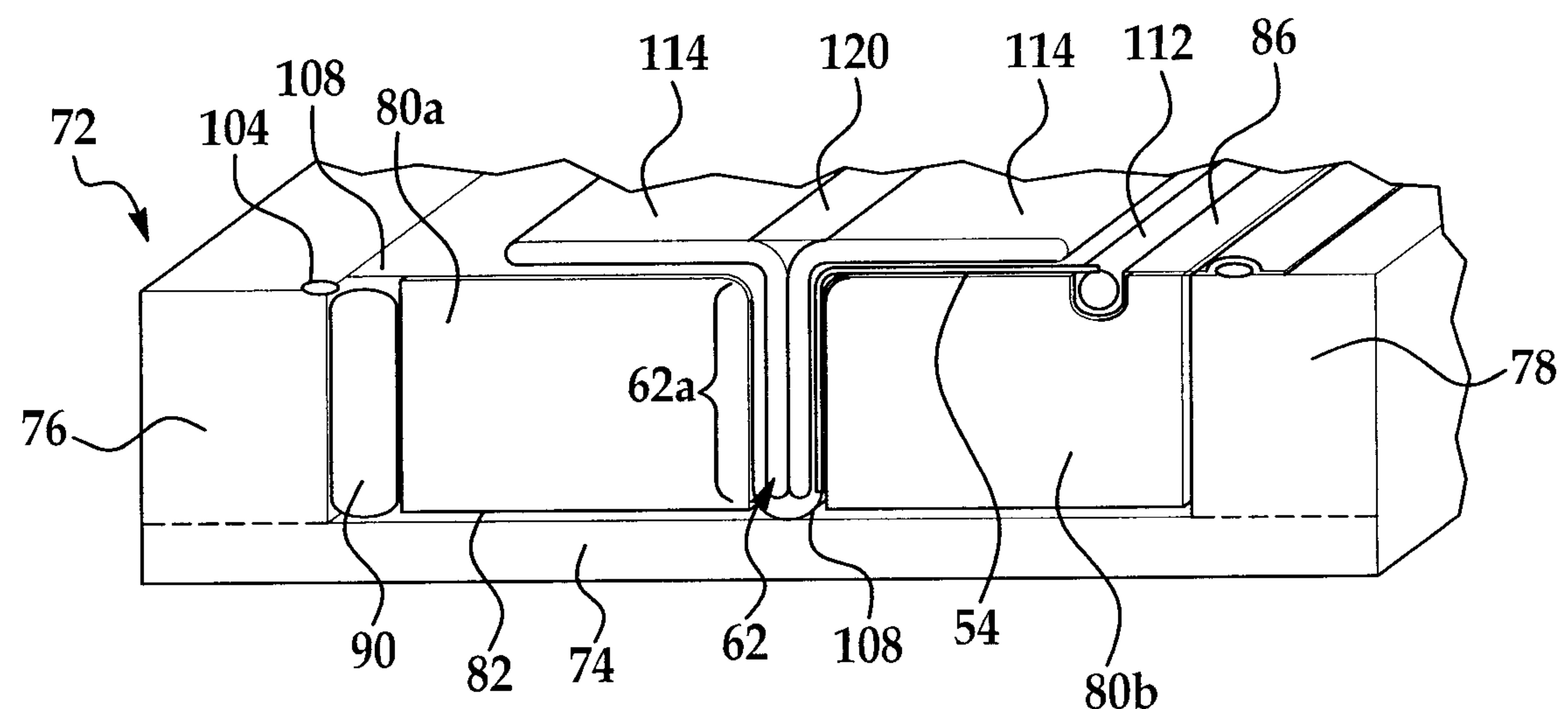


FIG. 20

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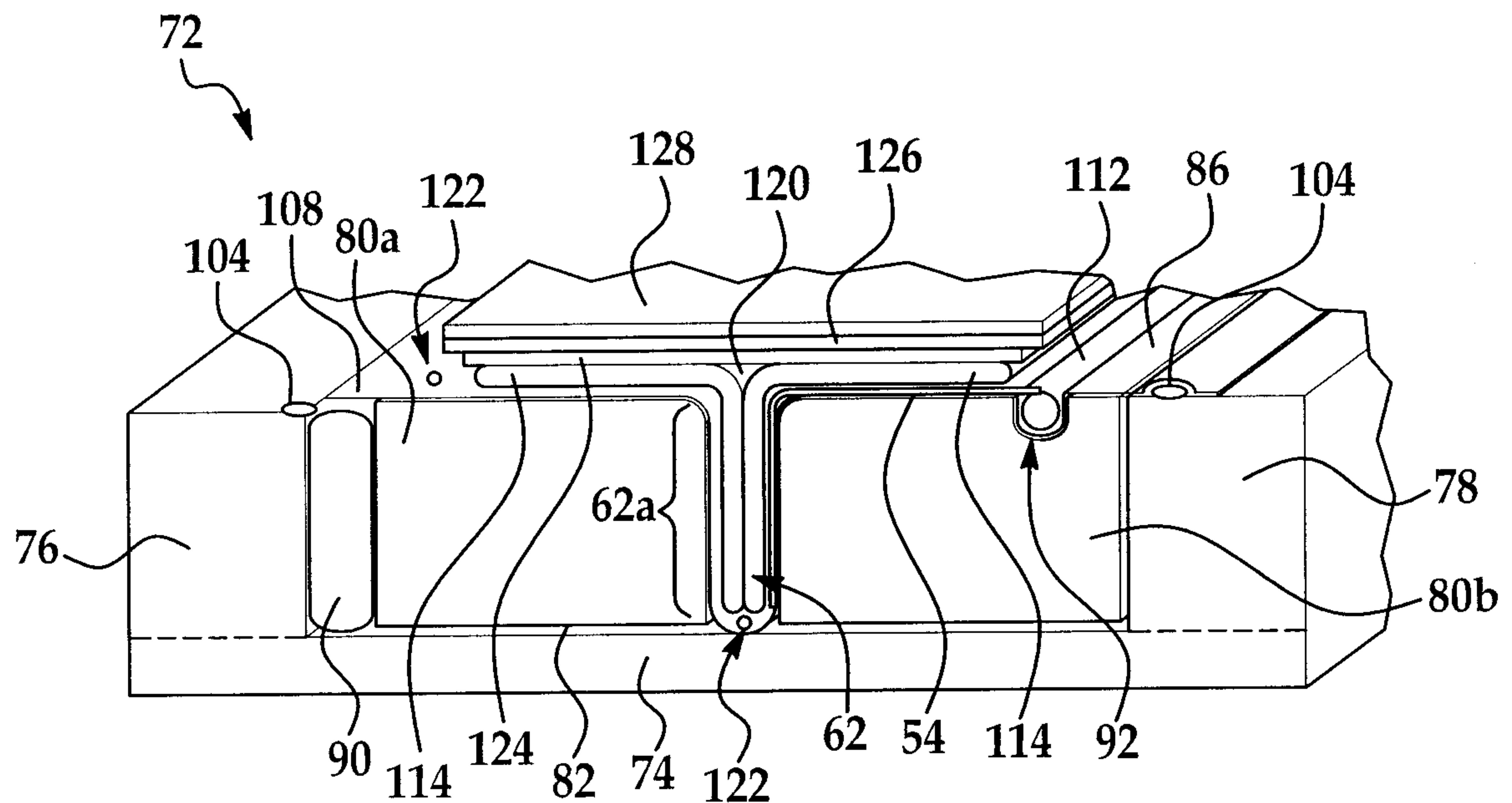


FIG. 21

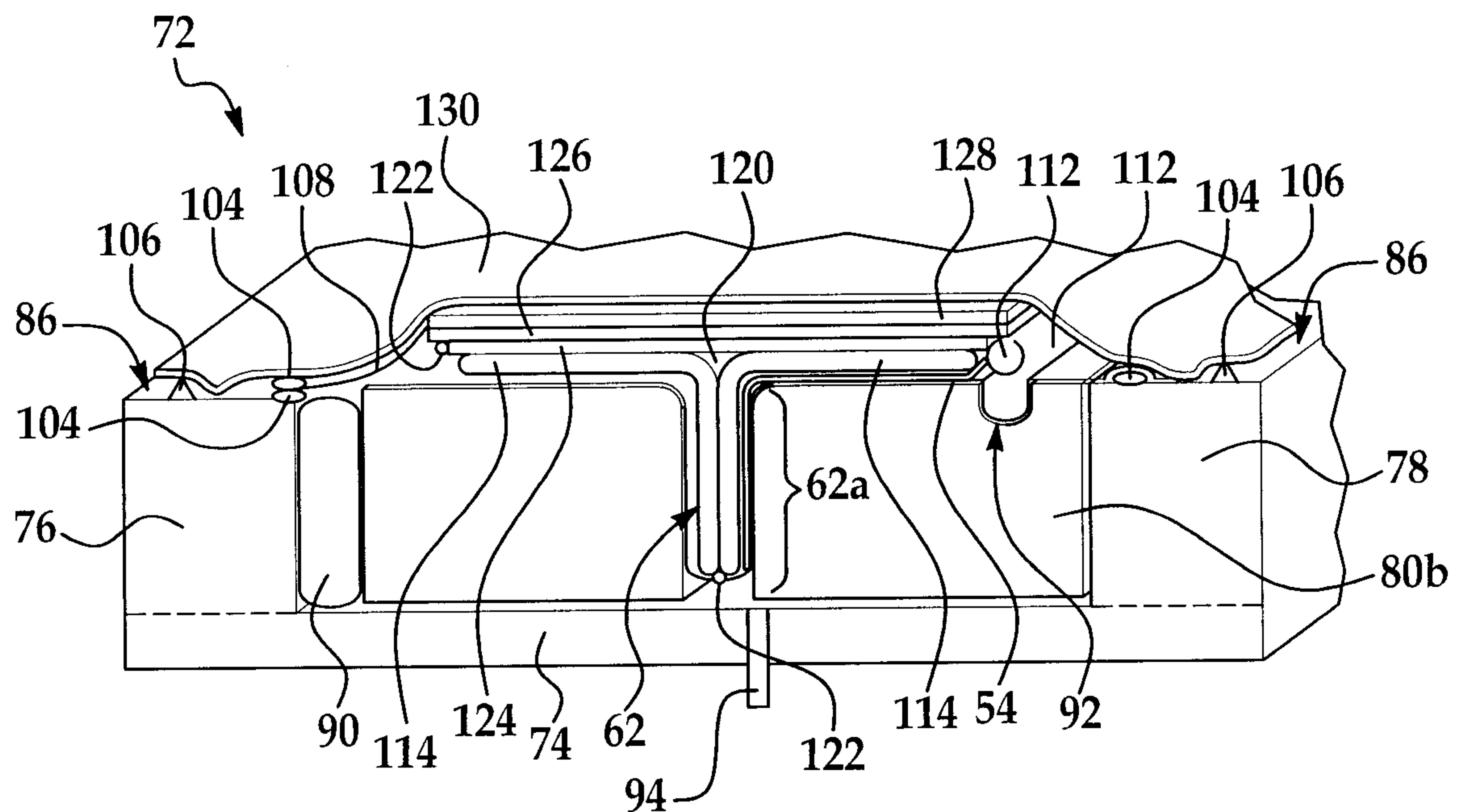


FIG. 22

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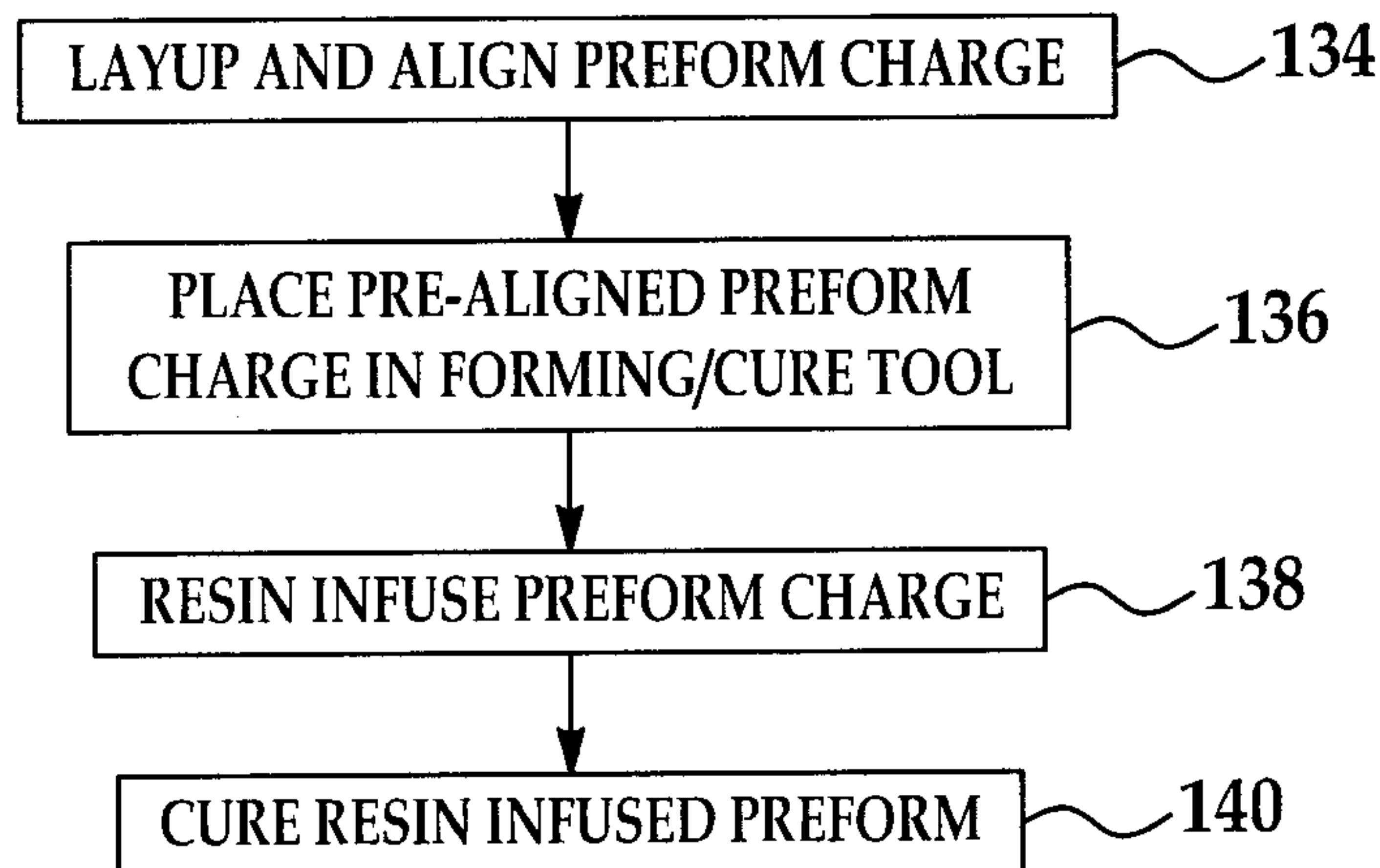


FIG. 23

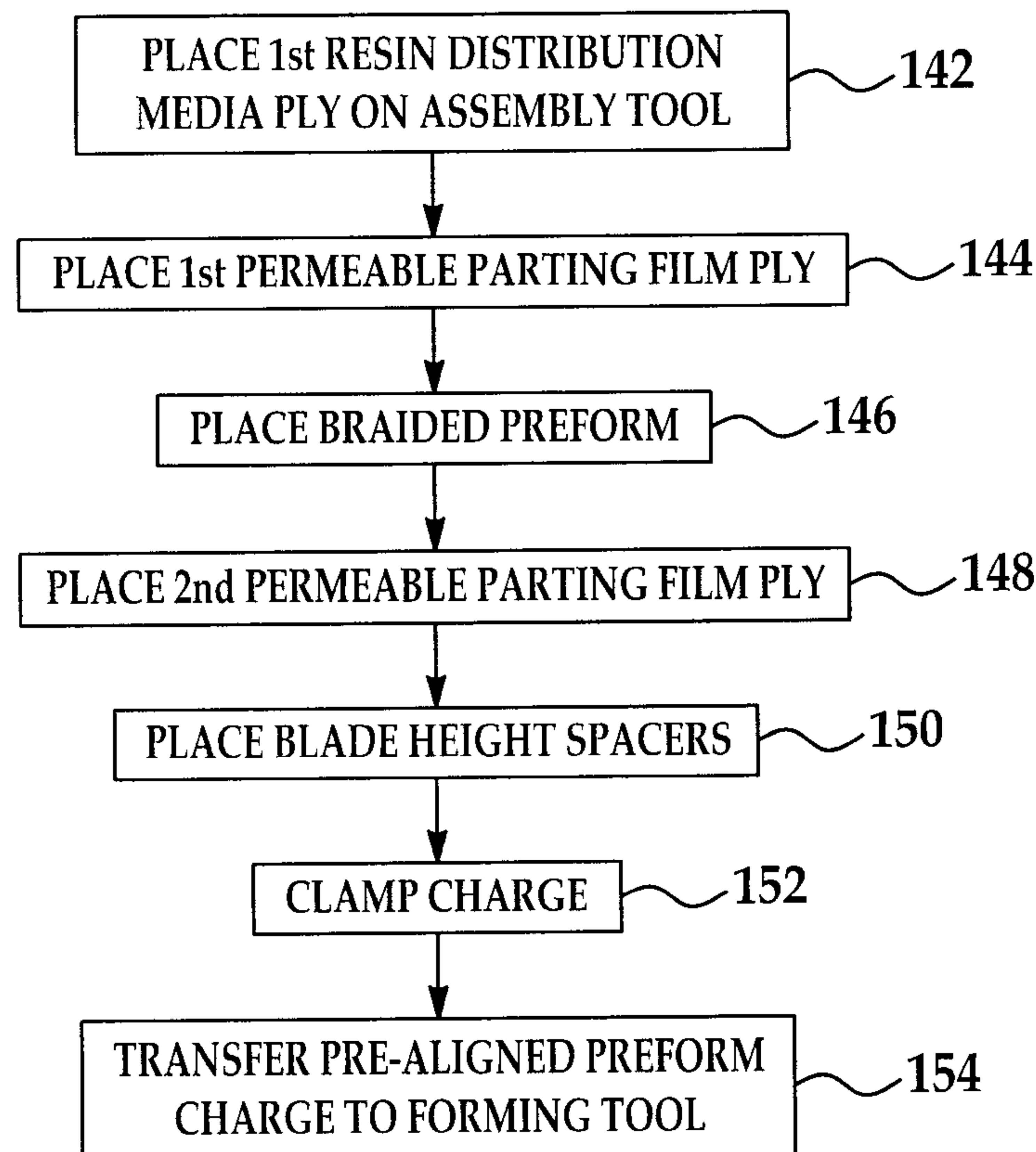


FIG. 24

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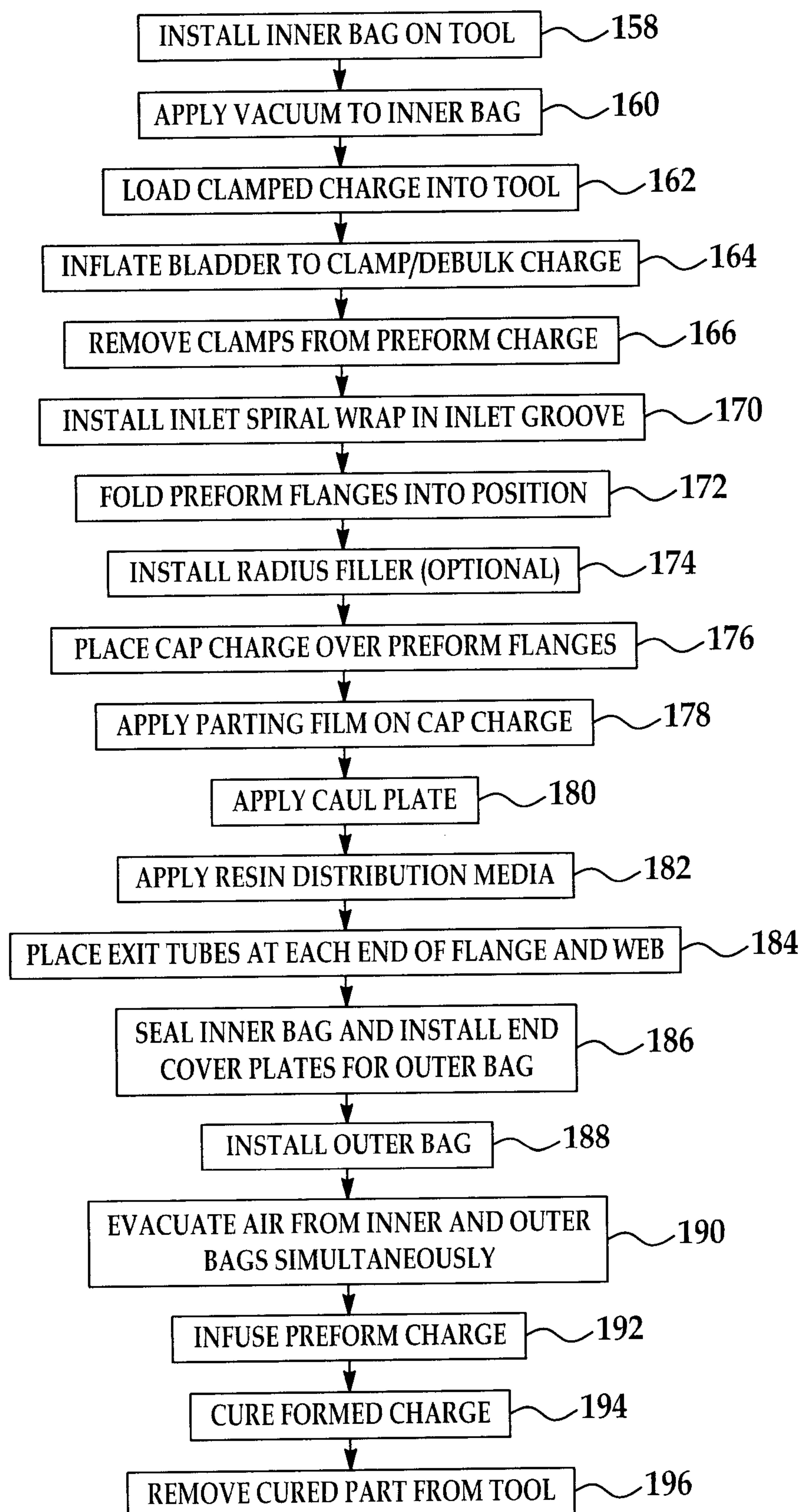


FIG. 25

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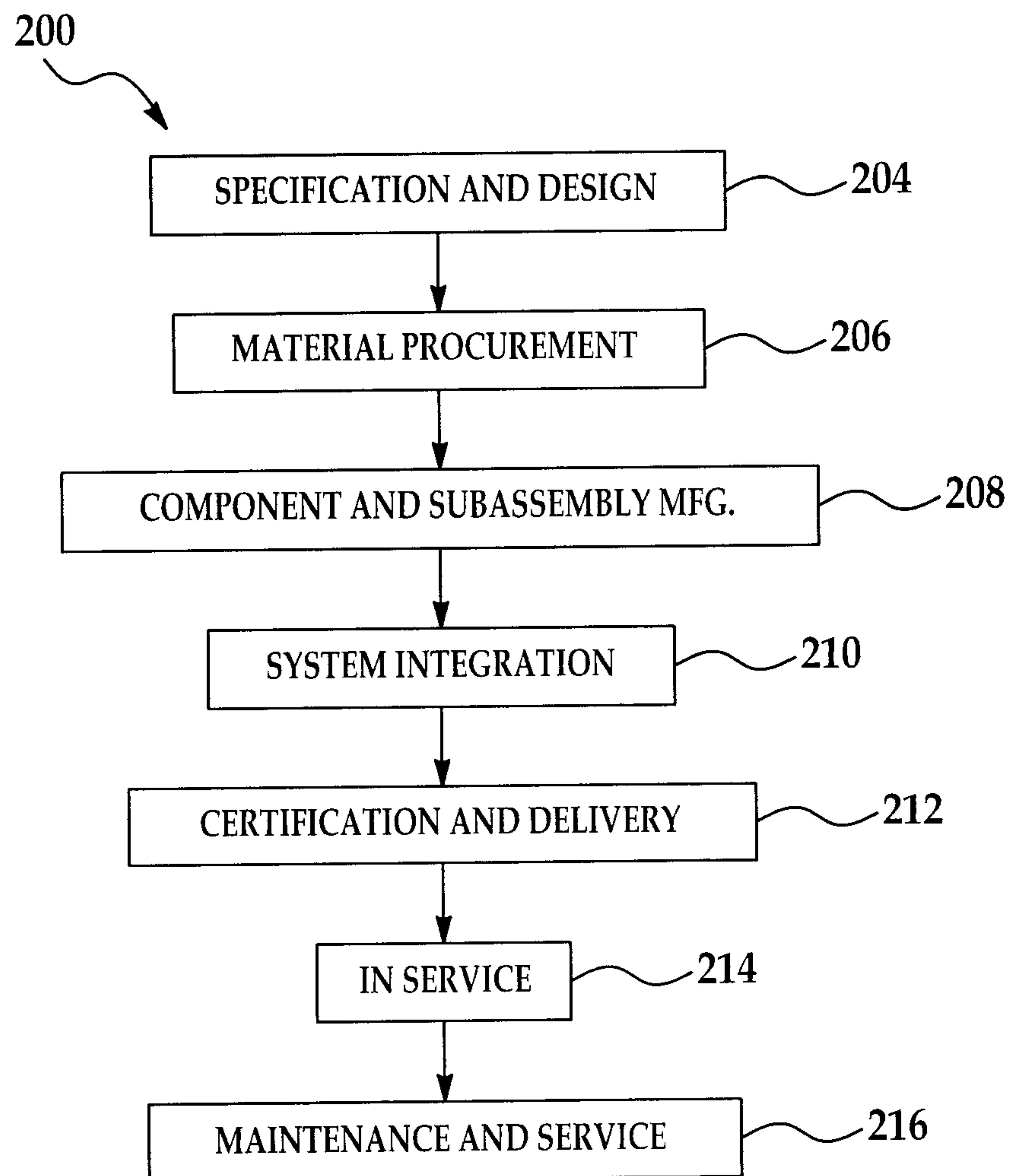


FIG. 26

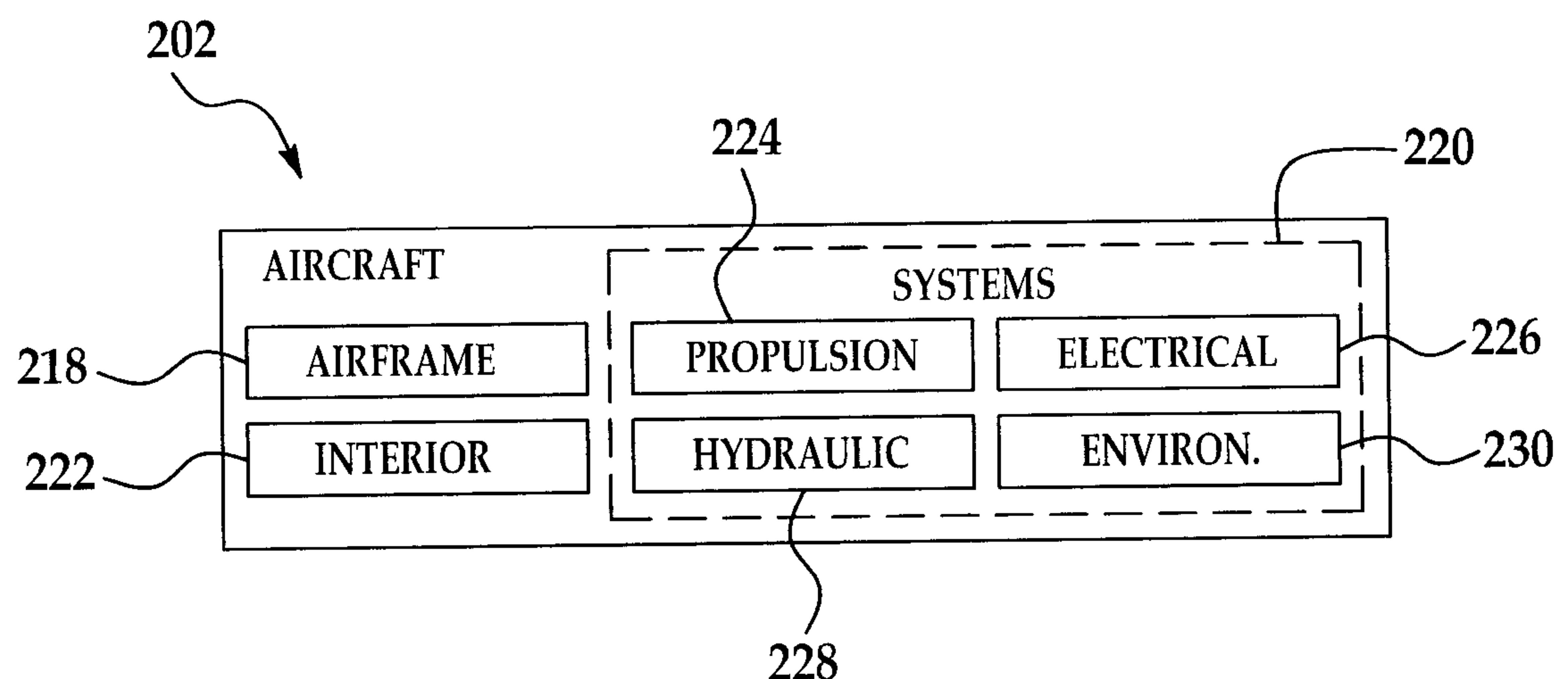


FIG. 27

