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(54) Titre : ENSEMBLES D'ELECTRODES A FAIBLE RESISTANCE A UTILISER POUR LA PRODUCTION DE METAUX

(54) Title: LOW RESISTANCE ELECTRODE ASSEMBLIES FOR PRODUCTION OF METALS

(57) **Abrégé/Abstract:**

An electrode assembly for use in a reduction cell for the production of metal such as aluminum. The electrode comprises an electrically conductive carbon electrode block with an electrically conductive metal member connected thereto. At least one solid, conductive metal insert is at least partly received in the carbon electrode block with an interference fit, such that the insert exerts a lateral force on the carbon electrode block. The insert provides an improved electrically conductive connection between the carbon electrode block and the conductive metal member, with reduced resistance. The insert may provide a direct connection between the electrode block and the metal member, or the connection may be provided through a layer of cast iron or other metal element provided between the electrode block and the metal member. The electrode assembly may either comprise an anode or a cathode.



ABSTRACT

An electrode assembly for use in a reduction cell for the production of metal such as aluminum. The electrode comprises an electrically conductive carbon electrode block with an electrically conductive metal member connected thereto. At least one solid, conductive metal insert is at least partly received in the carbon electrode block with an interference fit, such that the insert exerts a lateral force on the carbon electrode block. The insert provides an improved electrically conductive connection between the carbon electrode block and the conductive metal member, with reduced resistance. The insert may provide a direct connection between the electrode block and the metal member, or the connection may be provided through a layer of cast iron or other metal element provided between the electrode block and the metal member. The electrode assembly may either comprise an anode or a cathode.

LOW RESISTANCE ELECTRODE ASSEMBLIES FOR PRODUCTION OF METALS

TECHNICAL FIELD

[0001] The present subject matter relates to electrode assemblies for use in the electrolytic reduction of refined materials, including, but not limited to, use in aluminum reduction cells. The subject matter more specifically relates to the reduction of electrical resistance and improvement of the current distribution through the anode and cathode assemblies to reduce power consumption, to improve reduction cell performance and to improve operational life of the anodes and cathodes.

BACKGROUND

[0002] The Hall-Heroult process is a well known process for aluminum synthesis by electrolytic reduction of alumina. The process uses either pre-baked or in-situ baked carbon anodes paired in a reduction cell with opposing carbon cathodes that are separated from the anodes by a molten electrolyte ('bath') that contains dissolved alumina, and a molten metal pad of conductive aluminum overlying the top of the cathode. During the process an electrical current is passed between the anode and cathode to reduce the dissolved alumina into molten aluminum and to evolve carbon monoxide/or dioxide from the bottom of the anode. The conductive molten aluminum sinks to the aluminum layer or 'metal pad' on top of the carbon cathode, thereby becoming part of the electrical circuit. Alumina is added to the bath from an overhead hopper, while the molten aluminum is withdrawn from the reduction cell by intermittent siphoning to a mobile crucible.

[0003] The pre-baked carbon anode is attached to, and supported by, the lower end of a vertical conductor rod, and the upper end of the conductor rod is clamped to an electric buss beam. The vertical conductor rod is made of aluminum or copper and is typically joined to the carbon anode through a lower, horizontal

steel yoke and from one to eight (or more) round bar steel stubs attached to the yoke.

[0004] The carbon anodes are formed with prepared recesses (stub holes) in which the corresponding stubs are fitted. The stubs and anode are then joined by filling the space between them with cast iron or with carbon paste adhesive. When using cast iron for the bond the solidified iron annulus between the stub and carbon anode is referred to as a 'thimble'. The carbon anodes are mostly consumed in the reduction process by combining with the evolved oxygen from the reduced alumina. The anode assemblies have an operational duty life of typically 20-30 days in the reduction cell. A typical anode assembly of this type is disclosed in US Patent No. 3,398,081 to Bonfils et al.

[0005] Pre-baked cathode assemblies include a pre-baked carbon (carbonaceous or graphitic) cathode connected by cast iron or carbon paste to one or more steel current collector bars that are positioned in slots in the underside of the cathode. The collector bars are longer than the cathode and protrude through the reduction cell sidewall for connection to an electric buss. The cathodes have an operational duty life of typically 5-10 years, during which period the carbon corrodes, preferentially in electrical paths of lowest resistance and highest current density. The cathode blocks undergo sodium absorption from the bath, aluminum infiltration and vertical heaving from thermal stresses due to uneven temperature profile throughout the carbon, which conditions gradually increase the electrical resistance of the cathode assembly. When the resistance becomes too high or the drawn aluminum contains too much iron, that indicates dissolving collector bars, the reduction cell is removed from service to be relined with new material.

[0006] The electrical energy required to reduce alumina to aluminum and to heat the incoming alumina to the reduction temperature is a minor fraction of the total electrical energy typically consumed between the anode buss to cathode buss connections. The balance of energy consumed is from heat generated due to electrical resistance through the various components and connection interfaces of

the reduction cell circuit, which heat is removed to the environment. The factors influencing electrical resistance at the interfaces include the electrical resistance of the adjoining materials, the surface area and cleanliness of the interface, and the contact pressure between the adjoining materials. Although the cast iron connections used in the anode and cathode assemblies are electrically conductive, they still exhibit significant electrical resistance which generates ohmic heating that does not directly contribute to the electrolytic reduction process. The high electrical resistance is at least partly due to the shrinkage which the iron undergoes during solidification. This problem can be exacerbated by differential thermal expansion of the various materials of the electrode assemblies when the cell is heated to operating temperature.

[0007] Past efforts to improve the efficiency of electrolytic processes for metal production have either focused on improving the electrical current distribution through the anodes and cathodes, and/or reducing resistance between various components of the electrode assemblies. For example, a number of patents and published patent applications disclose thimbles having extensions to increase surface contact area with the anode, improving current distribution and reducing resistance. Examples of such constructions are disclosed in US Patent Nos. 4,552,638, 4,557,817 and 4,824,543. Others have attempted to change vertical current distribution through the thimble by adding undercuts or lateral extensions to the thimble (eg. US 4,621,674). Others have attempted to modify the contact pressure between the carbon electrodes and other components of the electrode assemblies, for example by providing an expanded graphite lining in the cathode collector bar slots (eg. US Patent No. 7,776,190 to Hiltmann et al.), or providing tapered, straight, or threaded connectors which are assembled with a low pressure fit with stress relief slots in the connection pin, or assembled with a loose fit, which pin expands and tightens only with increasing temperature (eg. US Patent Nos. 3,179,736, 3,390,071, 3,489,984 and 3,499,831). Others have used alternate materials and methods to provide separate mechanical and electrically conductive connections between the stub and anode (e.g. International Publication No. WO 2009/099335).

[0008] Despite the past efforts to improve the efficiency of electrolytic processes, there remains a need for anode and cathode assemblies which will help to achieve further reductions in the amount of energy consumed per kilogram of produced metal, reduced carbon emissions and carbon losses, and longer electrode life.

SUMMARY OF THE DISCLOSURE

[0009] In an embodiment, there is provided an electrode assembly for use in a reduction cell for the production of metal, the electrode assembly comprising: (a) an electrically conductive carbon electrode block having a first surface and a second surface, wherein the first surface faces an interior of the reduction cell when the electrode assembly is in use; (b) an electrically conductive metal member having a first end and a second end, wherein the first end of the metal member is connected to the carbon electrode block in an electrically conductive manner, and the second end of the metal member is adapted for connection to a buss bar in an electrically conductive manner; (c) a solid, conductive metal insert at least partly received in the carbon electrode block, wherein the insert extends into the carbon electrode block from the second surface thereof; and wherein the metal insert is received in the carbon electrode block with an interference fit, such that the insert exerts a lateral force on the carbon electrode block.

[00010] According to one aspect, the electrode is a pre-baked carbon anode, wherein the first surface of the carbon electrode block is a bottom surface thereof, and wherein the electrically conductive metal member comprises a vertical conductor rod. The electrically conductive metal member may further comprise a vertical stub at its first end, the carbon electrode block having a top surface opposite the bottom surface, a recess formed in the top surface, with an end of the vertical stub being received in the recess. The second surface in which the insert extends may comprise an inner surface of the recess, the inner surface being selected from a bottom surface and a side surface of the recess. For example, the insert may extend into the bottom surface of the recess and extend vertically

downwardly therefrom, and/or the insert may extend into the side surface of the recess and extend radially outwardly therefrom, with a portion of each said insert optionally protruding from the bottom surface or the side surface of the recess, the protruding portion optionally including an enlarged head. The insert may be inclined downwardly and outwardly from said second surface. A plurality of said inserts may be provided in the bottom surface and/or the side surface of the recess, with each of said inserts being at least partly received in the carbon electrode block.

[00011] According to another aspect, the recess may be provided with a conductive metal lining through which an electrically conductive connection is formed between the stub and the carbon electrode block, and wherein the insert or the plurality of inserts is in direct, electrically conductive contact with the conductive metal lining of the recess. At least a portion of the conductive metal lining may comprise a cast portion which is formed in situ between the stub and the carbon electrode block. For example, a portion of the conductive metal lining may comprise a solid preform which is combined with the cast portion during formation of the metal lining, and wherein the insert or the plurality of inserts is in direct, electrically conductive contact with the preform prior to formation of the cast portion. The preform may comprise a bottom plate which is in contact with a bottom surface of the recess.

[00012] According to yet another aspect, the electrode assembly may further comprise a plurality of said vertical stubs at its first end, the stubs being spaced apart from one another, with the carbon electrode block having a plurality of said recesses formed in its top surface, with an end of each of the vertical stubs being received in a corresponding one of the recesses; and wherein each of the vertical stubs is secured to the vertical conductor rod through an electrically conductive metal yoke. The electrode assembly may further comprise a plurality of electrically conductive bypass members, each of which bypasses the yoke and one of the vertical stubs, wherein each of the bypass members has a first end connected to the vertical conductor rod through an electrically conductive connection, and a

second end connected to the carbon electrode block through an electrically conductive connection. The carbon electrode block is provided with a plurality of said inserts in the top surface thereof, and wherein the second end of each of the bypass members is connected to at least one of the inserts. The second end of each bypass member may be secured to the top surface of the electrode by at least one of the inserts, and wherein the second end of each bypass member includes an expandable or flexible portion.

[00013] According to yet another aspect, the carbon electrode block has a top surface opposite the bottom surface, and is provided with a plurality of said inserts in the top surface thereof, wherein the electrode assembly further comprises a collar-shaped connector having a side wall to receive the first end of the electrically conductive metal member and to provide an electrically conductive connection between the electrically conductive metal member and the carbon electrode block, and wherein the collar-shaped connector further comprises at least one attachment portion which is connected to the side wall and extends outwardly therefrom, each of the attachment portions being connected to at least one of the inserts to provide an electrically conductive connection between the attachment portion and the at least one of said inserts. The plurality of said inserts may be distributed across the top surface of the carbon electrode block, with the attachment portion(s) connected to each of the inserts. The electrically conductive metal member may further comprise a vertical stub at its first end, wherein each of the vertical stubs is secured to the vertical conductor rod through an electrically conductive metal yoke; the electrode assembly further comprising a plurality of said collar-shaped connectors, and the sidewall of each collar-shaped connector receiving an end of one of the vertical stubs; and each of the attachment portions is conductively connected to all of the vertical stubs through the collar-shaped connectors.

[00014] According to yet another aspect, carbon electrode block has a top surface opposite the bottom surface, and is provided with a plurality of said inserts in the top surface thereof, wherein the electrode assembly further comprises a yoke assembly through which an electrically conductive connection is provided between

the electrically conductive metal member and the carbon electrode block; wherein the yoke assembly comprises a plurality of curved metal struts, each having an upper end and an opposed lower end, the upper end being secured by an electrically conductive connection to the lower end of the electrically conductive metal member, the lower end being secured to the carbon electrode block with an electrically conductive connection by at least one of said inserts. The lower ends of the struts may extend outwardly away from one another and from the electrically conductive metal member, and the yoke assembly may include a pair of said struts, oppositely disposed relative to one another.

[00015] According to yet another aspect, the electrode is a pre-baked carbon cathode, wherein the first surface of the carbon electrode block is a top surface thereof and the carbon electrode block has a bottom surface opposite the top surface, and wherein the electrically conductive metal member comprises a current collector bar having an end received in a slot in the bottom surface, the current collector bar and the bottom surface being substantially parallel. A cast iron layer may be provided in the slot, between the current collector bar and the carbon electrode block. The second surface in which the insert extends may comprise an inner surface of the slot, the inner surface of the slot being selected from a top surface and a side surface of the slot. The insert may have a flat head which is received between the cast iron layer and the carbon electrode block, and a conductive metal liner and/or a conductive metal washer may be received between the flat head of the insert and the carbon electrode block.

[00016] According to yet another aspect, the current collector bar is provided with one or more collector bar anchors, each said anchor having a first end attached to the collector bar and a second end embedded in the cast iron layer. For example, the first end of each said anchor comprises a threaded shank which is received in a threaded bore in the collector bar.

[00017] According to yet another aspect, the second surface in which the insert is received comprises the bottom surface of the carbon electrode block, the current

collector bar having a flat bottom surface which is substantially co-planar with the bottom surface of the carbon electrode block. An electrically conductive metal connector may be attached to the bottom surface of the carbon electrode block and to the flat bottom surface of the current collector bar, to provide an electrically conductive connection between the current collector bar and the carbon electrode block. The electrically conductive metal connector may be attached to the top surface of the carbon electrode block by said insert, and is in electrically conductive contact with said insert. The electrically conductive metal connector is in the form of one or more layers of flat metal strap. The strap may have an expandable portion to permit deformation of the electrically conductive metal connector in response to differential thermal expansion of the current collector bar and the carbon electrode block, along an axis defined by the current collector bar. Alternatively, the electrically conductive metal connector may comprise a flexible cable connector, which may be provided with lug ends.

[00018] According to yet another aspect, the electrode assembly may comprise a plurality of said inserts provided in the bottom surface of the carbon electrode block, with each of said inserts being at least partly received in the carbon electrode block, and the electrode assembly may further comprise a plurality of said electrically conductive metal connectors, each providing an electrically conductive connection between the current collector bar and at least one of the inserts. The inserts may be spaced apart along a length of the carbon electrode block, and/or the inserts may be of different dimension to control the resistance of the top surface of the carbon block relative to the external portion of the collector bar.

[00019] According to yet another aspect, a thickness of the insert and the width of the bore are sized relative to one another such that an interface contact pressure between the insert and the adjoining carbon electrode block is at least about 1 kPa. For example, the interface contact pressure may be less than about 10 MPa, and/or the interface contact pressure may be between about 1 MPa and about 10 MPa. A maximum interface contact pressure may be less than about one

half of the breaking pressure required to break the surrounding carbon electrode block.

[00020] According to yet another aspect, the second end of the metal member, which is adapted for connection to the buss bar, includes a connecting surface which is adapted to mate with the buss bar, and wherein the connecting surface is electroplated or clad with corrosion resistant conductive material.

[00021] According to yet another aspect, the insert is received in a bore either pre-drilled or formed in the carbon electrode block.

[00022] According to yet another aspect, the electrode is pre-baked and the insert is inserted into the carbon electrode block either before or after the electrode is pre-baked.

[00023] According to yet another aspect, the current collector bar is supported within the slot of the carbon electrode block by at least one hanger assembly comprising a tongue portion slidably received in a slot portion. The slot portion may be secured to the carbon electrode block by one or more of said conductive metal inserts, and the tongue portion is secured to the current collector bar.

BRIEF DESCRIPTION OF THE DRAWINGS

[00024] In order that the claimed subject matter may be more fully understood, reference will be made to the accompanying drawings, in which:

[00025] Figure 1 is a cross section through a reduction cell as described herein;

[00026] Figures 2 and 3 are perspective views showing the stubs of an anode assembly before and after insertion into the stub holes of the anode block;

[00027] Figures 4 and 5 are perspective views showing the casting of the thimble in the anode of Figures 2 and 3;

[00028] Figure 5a is an enlarged, partial vertical cross-sectional view through the stub, thimble and anode block of the anode of Figure 5;

[00029] Figures 6 and 7 are perspective views showing the electrode of Figure 5 provided with electrically conductive bypass members;

[00030] Figure 8 is a partial, perspective cross-sectional view, showing a recess for receiving a stub according to an embodiment described herein;

[00031] Figure 8a is a close-up, cut-away view of an insert embedded in the wall of the stub hole shown in Figure 8;

[00032] Figure 9 is a partial, perspective cross-sectional view, showing a recess for receiving a stub according to another embodiment described herein;

[00033] Figure 9a shows a preform for formation of a thimble according to an embodiment described herein;

[00034] Figure 10 is a cut-away side elevation view showing an electrode with thimble anchors;

[00035] Figures 11 and 12 show an electrode assembly including an assembly for attaching the stubs to the top surface of the anode block;

[00036] Figure 13 is a perspective view of an electrode assembly having a low resistance yoke assembly as described herein;

[00037] Figures 14a to 14e are side views of various types of conductive inserts and connections as described herein;

[00038] Figures 15 and 16 are perspective views showing the casting of a cast iron layer in a cathode assembly;

[00039] Figure 17 is a perspective view showing a cathode block in which the connection to the collector bar is provided by a plurality of strap connectors;

[00040] Figure 18 is a side view of the cathode block of Figure 17;

[00041] Figure 19 is a partial transverse cross-section through a cathode block showing an embodiment in which the connection to the collector bar is provided by an alternate form of strap connector;

[00042] Figure 20 is a partial perspective view of a cathode block, partly in cross-section, showing another embodiment in which the connection to the current collector bar is provided by an alternate form of strap connectors;

[00043] Figure 21 is a perspective view of a steel cathode collector bar with a conductive metal surface cladding;

[00044] Figure 22 is a partial view of the slot of a cathode assembly according to an embodiment disclosed herein;

[00045] Figure 23 is a perspective view showing a portion of a conductive lining for a cathode slot;

[00046] Figure 24 is a partial view of the slot of a cathode assembly according to another embodiment disclosed herein; and

[00047] Figures 25 to 28 are views of cathode assemblies, showing alternate methods for connecting the current collector bar to the cathode block.

DETAILED DESCRIPTION OF EMBODIMENTS

[00048] Certain embodiments are now described below with reference to the Hall-Heroult process for aluminum synthesis by electrolytic reduction of alumina. However, it will be appreciated that the embodiments described herein may be modified for use in other electrolytic reduction or electrolysis processes for the production of metals or chemicals that may also use metal electrodes joined to carbon anodes or cathodes, including but not limited to the electrolytic reduction of Lithium, Sodium and Magnesium.

[00049] Although pre-baked anode technology has developed over time to larger anodes with larger or more stubs, and to larger reduction cells with higher applied amperage, the subject matter disclosed herein may be applied to all forms and configurations of pre-baked carbon anodes and pre-baked carbon cathodes. Furthermore, the subject matter disclosed herein for the thimble anchors or preform may be applied either before or after the anode is baked, the carbon material of the anode being referred to herein as "green" prior to baking.

[00050] Figure 1 is a cross-sectional view showing the components of a reduction cell 10 for aluminum production. The reduction cell 10 includes a plurality of opposed electrode assemblies, including a plurality of anode assemblies 12, of which two are shown in Figure 1, and a plurality of cathode assemblies 14, of which one is shown in Figure 1.

[00051] Each electrode assembly 12, 14 comprises an electrically conductive carbon electrode block having a first surface and a second surface, wherein the first surface faces the interior 16 of the reduction cell 10 when in use. In this regard, each anode assembly 12 includes a carbon anode electrode block 18 (also referred to herein as the "anode block 18") and each cathode assembly includes a carbon cathode electrode block 20 (also referred to herein as the "cathode block 20"), which are described in more detail below. The first surface of each anode block 18 is the lower surface 22, and the first surface of each cathode block 20 is the upper surface 30. As shown in Figure 1, the surfaces 22, 30 face one another and face the interior 16 of the reduction cell 10.

[00052] The interior 16 of reduction cell 10 contains a molten electrolyte bath 26 which contains dissolved alumina, and a molten metal pad 28 of conductive aluminum overlying the top surface 30 of the cathode block 20. As alumina is reduced to aluminum, it sinks into the molten pad 28 and becomes part of the electrical circuit. Alumina is added to the bath 26 from an overhead hopper 32, while the molten aluminum is withdrawn from the metal pad 28 by intermittent siphoning to a mobile crucible (not shown). The interior 16 of reduction cell 10 is enclosed by sidewall refractories 34 and bottom refractory 36.

[00053] Each electrode assembly 12, 14 further comprises an electrically conductive metal member having a first end and a second end, wherein the first end of the metal member is connected to the carbon electrode block 18 or 20 in an electrically conductive manner, and the second end of the metal member is adapted for connection to a buss bar in an electrically conductive manner.

[00054] In this regard, the electrically conductive metal member 37 of each anode assembly 12 comprises a vertical conductor rod 38 which is typically made of aluminum or copper, the first (lower) end 40 of conductor rod 38 being connected to the top surface 42 of the anode block 18, and the second (upper) end 44 of which is connected to an anode buss bar 46, for example by clamping or the like. It will be appreciated that the electrically conductive metal member 37 carries

electric current from the anode buss bar 46 to the anode block 18, and also suspends the anode block 18 in the bath 26.

[00055] The electrically conductive metal member 37 of each anode assembly 12 further comprises one or more vertical stubs 48 at its first end 40. In the reduction cell shown in Figure 1 the anode assemblies 12 each have two stubs 48 which are spaced apart from one another along the top surface 42 of the anode block 18. However, it will be appreciated that the anode assembly may comprise a single stub 48, or more than two stubs 48. The stubs 48 are typically comprised of steel and typically have a cylindrical shape, although the stubs 48 may have other cross-sectional shapes, such as square or rectangular.

[00056] The electrically conductive metal member 37 of each anode assembly 12 further comprises an electrically conductive metal yoke 50 through which the stubs 48 are connected to the lower end 40 of the vertical conductor rod 38. The yoke 50 comprises a horizontal member such as a thick conductive plate of steel or other conductive metal. Alternatively, the yoke 50 may be integrally formed with the stubs 48.

[00057] The electrically conductive metal member of each cathode assembly 14 comprises a current collector bar 52. A section of the collector bar 52 is located within the cell 10 and is connected to the cathode block 20. One or both ends of the collector bar 52 are located external of the cell 10 and connected to a cathode buss 24 located outside the cell 10. Therefore, as shown in Figure 1, the collector bar 52 extends through the sidewall refractory 34 on one or both sides of the cell 10. The cathode block 20 has a bottom surface 54 opposite the top surface 30. The collector bar 52 may be split in two pieces (not shown) and separated in the middle of the cathode block 20, each piece having one end and a portion of the collector bar 52 connected to the cathode block 20 and the opposite end protruding through the refractory sidewall 34 of reduction cell 10 and connected to the cathode buss 24 located outside the cell 10.

[00058] As shown most clearly in the isolated views of Figures 15 and 16, the bottom surface 54 of the cathode block 20 has an elongate slot 56, open at the bottom surface 54, in which the end of the current collector bar 52 is received. The cathode block 20 and the current collector bar 52 may be connected by a layer of cast iron 57 or carbon paste provided between the interior surfaces of the slot 56 and the current collector bar 52.

[00059] During operation, the cathode blocks 20 undergo sodium absorption from the bath 26, aluminum infiltration from the metal pad 28, and thermal stresses between the top and bottom surfaces 30, 54 due to uneven temperature profile throughout the carbon, which conditions gradually cause an upward bowing of the cathode block 20 which increases the electrical resistance of the cathode assembly 14. When the resistance becomes too high, or the cathode block 20 corrodes to the extent of allowing aluminum contact with the collector bars 52, the reduction cell 10 is removed from service to be relined with new material.

[00060] Figures 2 to 5 illustrate a conventional anode assembly 12 having an anode block 18 of generally rectangular shape, a vertical conductor rod 38 of rectangular cross-section and a horizontal yoke 50 integrally formed with a pair of vertical stubs 48, the yoke 50 being conductively connected to the lower end of the conductor rod 38 by welding, brazing or the like and typically on either side of a bimetallic transition joint 51. After the anode assembly 12 is clamped and suspended from the anode buss 46, the top surface 42 of the anode block 18 is covered with a layer consisting of a combination of frozen crystalline bath and powdered alumina, called a "bath cover" 25, (Fig. 1) to prevent air contact with the top surface 42 of the anode block 18 and to insulate the anode 12 from excess heat loss.

[00061] Figures 2 and 3 illustrate the insertion of the lower ends of vertical stubs 48 into recesses 58 formed in the top surface 42 of the anode block 18, the recesses 58 sometimes being referred to herein as "stub holes". As best seen in the enlarged views of Figures 8, 8a and 9, the recesses 58 have a generally

cylindrical shape to match that of the stubs 48, the inner surface of each recess 58 comprising a flat, horizontal, circular bottom surface 60, and a generally cylindrical side surface 62, which may be tapered to have a smaller diameter at its bottom than at its top. The side surface 62 may be provided with helical grooves 66, as disclosed in above-mentioned US Patent No. 3,398,081 to Bonfils et al.

[00062] The stubs 48 and recesses 58 have diameters such that an annular gap is provided between the vertical side surface of each stub 48 and the cylindrical side surface 62 of each recess 58. Figures 4 and 5 illustrate the formation of a conductive metal lining 64, also referred to herein as a "thimble", in the gap between the stub 48 and the inner surface of the recess 58, to provide an electrically conductive connection between each stub 48 and the anode block 18. The metal lining 64 is at least partially cast in situ, i.e. with the stub 48 received in the recess 58, and with the bottom of the stub either in contact with or in close proximity to the bottom surface 60, where molten metal 27 such as cast iron is poured into the annular recess between the stub 48 and the inner surface of recess 58. The metal lining 64 is typically formed from cast iron, the brittle nature of which makes it easy to remove from the steel stubs 48 during anode 12 recycling procedures.

[00063] Upon rapidly freezing the thimble 64 in situ from molten iron, the iron undergoes solidification shrinkage. As shown in Figure 5a, the iron solidifies with freeze isotherms 29 primarily parallel to the vertical surface of the stub 48, which acts as a heat sink, and further undergoes three dimensional thermal shrinkage of the solid iron upon cooling of the thimble 64 from its freezing temperature down to its lower operating temperature. The shrinkage of the iron causes a vertical gap 31 and a loose fit between the outer surface of the thimble 64 and inner surface of recess 58.

[00064] Similarly, with reference to Figures 15 and 16, the cathode collector bar 52 is received in the slot 56 of the cathode block 20 with a space provided between the collector bar 52 and the walls of slot 56. This space is filled with a

layer 57 of cast iron formed in situ against the collector bar 52 by pouring molten metal 27 into the space between the collector bar 52 and the walls of slot. For the same reasons described above with reference to the anode 12, a gap may form between the surfaces of the slot 56 and the outer surface of the cast iron layer 57 due to shrinkage of the metal of layer 57. During initial heatup of the reduction cell 10, the steel stub 48, collector bar 52, cast iron connections 57, 64 and carbon electrode blocks 18, 20 expand at different rates, and a high carbon cast iron may expand slightly by undergoing phase transition, all providing a tighter fit of the assembly than when cold, however still with considerable electrical resistance through each of the electrode assemblies 12 and 14.

[00065] The electrical current distribution through the anodes and cathodes follow the paths of least resistance, passing from the power connection points at the anode buss 46 to the external ends of the collector bars 52. This electrical current behavior results in uneven electrical resistance and current density across the first surfaces of the blocks 22, 30 to the bars 38 and 52 respectively, which in turn may cause uneven anode consumption and uneven cathode wear and corrosion. The uneven electrical resistance across the top surface 30 of the cathode block 20 may also contribute to horizontal electrical flow through the aluminum metal pad 28 due to the aluminum's very low electrical resistance, which horizontal electrical flow generates electromagnetic flow currents and turbulence (waves) in the metal pad 28. This turbulence may force a larger than normal anode to cathode distance (ACD) to be maintained to avoid short circuits between the bottom surface of anode block 18 and the top surface 30 of cathode block 20, which additional ACD incurs extra electrical resistance through the bath 26, consuming more electrical energy than otherwise required for the reduction process.

[00066] The present subject matter addresses the above problems by providing solid conductive metal inserts 76 received in the carbon electrode blocks 18 and/or 20 of the electrode assemblies 12, 14, with an interference fit, and with or without accompanying bores 68 (also referred to herein as "boreholes") in the carbon electrode blocks 18 and/or 20. One end of each insert 76 is embedded into

the carbon of the electrode block 18 or 20, with a controllable lateral interface contact pressure between the insert 76 and the carbon, which pressure provides a low resistance electrical path into the carbon, thereby reducing power consumption. The application of the interference fit inserts 76 varies between the anode 12 and cathode 14, but follows the same general principle.

[00067] As defined herein, an interference fit is one which produces a high 'lateral' interface pressure between the insert 76 and the carbon material of the electrode block 18 or 20, i.e. the pressure being directed radially outwardly against the carbon material. The high lateral interface pressure reduces the electrical resistance across the 'lateral' interface between the insert 76 and the carbon material. Alternatively, or in addition to the high lateral interface pressure, the interference fit may provide an axial (i.e. along an axis defined by insert 76) compression or interference fit with high contact pressure between the outer surface of the insert 76 and the carbon material. To produce an interference fit the inserts 76 must be inserted into the solid carbon material, as opposed to being formed by solidifying a molten metal poured or injected into a recess or cavity, which would be subject to shrinkage upon solidification and which, in any event, would not achieve significant interface pressure to provide an interference fit.

[00068] The controlled, high contact pressure between the insert 76 and the carbon electrode block 18 or 20 may cause minor carbon material failure local to the interface (by crushing or scaling), which limited carbon failure is acceptable provided that such carbon failure does not extend to cracks through the carbon electrode block 18 or 20 which may introduce high electrical resistance areas across the crack, or which cracks may propagate during operation causing the anode or cathode electrode block 18 or 20 to physically break apart. Use of inserts 76 providing an interference fit therefore requires consideration of the mechanical stresses induced by thermal expansion of the insert within the carbon anode or cathode electrode block 18 or 20 when placed in operation, and the strength of the anode or cathode electrode block 18 or 20 relative to the location of the insert 76 determined by the lateral thickness of carbon surrounding the insert 76. The

interface pressure may change during the operational life of the anode 12 or cathode 14 due to material creep, depending on the temperature and thermal behaviour of the adjoining materials. The breaking strength of the anode 12 or cathode 14 may also change due to its temperature and condition over its operational life. The interface pressure and resulting electrical resistance of the connection can be controlled by adjusting the external dimensions of the insert 76 and/or the dimensions of bores 68 (e.g. drilled pilot holes, etc.) in the carbon material, in order to control the amount of interference fit, contact area and resulting contact pressure.

[00069] The interference fit between the insert 76 and the carbon material of the electrode block 18 or 20 is such that an interface contact pressure between the insert 76 and the carbon material of the adjoining electrode block 18 or 20 is at least about 0.1 kPa. For example, the interface contact pressure is typically up to about 10 MPa, and/or between about 1 MPa and about 10 MPa. Interface contact pressures in excess of 10 MPa, although possible, do not significantly further reduce the electrical resistance across the interface and increase the risk of cracking of the carbon substrate.

[00070] To avoid cracking the carbon electrode block 18 or 20, the pressure applied by the interference fit may be less than about one half of the stress required to break the carbon electrode block 18 or 20. The breaking pressure depends on the strength of the carbon material of the carbon electrode block 18 or 20 and the minimum width and thickness of carbon material surrounding the insert 76. It will be appreciated that the breaking pressure may vary in different regions of the electrode block 18 or 20, being higher in the middle of the block than near its edges.

[00071] The total applied pressure caused between the insert and the surrounding carbon material of the electrode block 18 or 20 depends on the contact area between them. Limiting the surface area of the insert 76 within the carbon material, with or without a bore 68, can enable a high interface pressure with a

limited total applied pressure. Selecting a maximum applied pressure of less than approximately one half of the minimum yield strength of the surrounding carbon should provide an adequate margin of error, such that the anode or cathode electrode block 18 or 20 does not break from extra pressure that may result during anode and cathode operation, possibly due to greater thermal expansion of the inserts 76 versus the carbon of the carbon electrode block 18 or 20, and the potential weakening of the carbon electrode block 18 or 20 from bath absorption and air burn during its operational cycle. In the alternative, the interface pressure for each insert 76, with or without a bore 68, may be theoretically determined using Lames equation for interference fit. The selection of dimensions, locations and quantity of inserts 76 are to take into consideration an acceptable current density through the inserts 76 and desired current distribution through the anode or cathode electrode block 18 or 20. The maximum interface pressure may also be tested experimentally for each insert 76 location prior to implementation in the reduction cell 10.

[00072] The inserts 76 will typically be inserted into the electrode block 18 or 20 after it has been formed and baked to a hardened state, producing an interference fit as described above. However, it will be appreciated that the inserts 76 may be inserted into the electrode block 18 or 20 after it has been formed, and while it is in a green state, i.e. prior to baking. Where an insert 76 is installed into the carbon of the electrode block 18 or 20 prior to baking, the carbon is relatively soft and the interface contact pressure between the insert 76 and the surrounding carbon will initially be low. The electrode block 18 or 20 will then be hardened by baking, with the insert 76 installed therein, and a good electrical bond between the insert 76 and the surrounding carbon of the electrode block 18 or 20 will result.

[00073] The current density and resistance through the inserts 76 and between the inserts 76 and the surrounding carbon material of electrode block 18 or 20 will generate ohmic heating that will heat the inserts 76, which temperature should be maintained below the point at which the yield strength of the heated insert 76 falls below two times the desired interface contact pressure between the insert 76 and

the surrounding carbon material, taking into account any additional load that any insert 76 may carry, for example due to the mass of the suspended carbon block 18 in the case of anode 12.

[00074] When the inserts 76 are used within the anode assembly 12, specifically between the anode block 18 and the cast iron thimble 64, the insert 76 is sometimes referred to herein as a 'thimble anchor'. The thimble anchor 76 enhances the mechanical and electrical connections between the thimble 64 and the anode block 18. A portion of the thimble anchor 76 is embedded in the anode block 18 with an interference fit, as defined above, between the thimble anchor 76 and the surrounding carbon material of the anode block 18. The total interface contact area between the insert and the anode block 18 depends on the diameter, embedded length and quantity of the inserts 76 used. When using large diameter inserts 76, then a predrilled borehole 68 may be provided for the insert 76 to be embedded into, in order to limit the maximum lateral interface contact pressure to avoid fracture of the carbon of the anode block 18. The inserts 76 may be impact driven if nail style, or screwed into the carbon if screw or bolt style, either with or without a borehole 68 to provide the desired interface contact pressure. The inserts 76 may also be in the form of expansion anchors that are loose fit inserted into predrilled boreholes 68 and then tightened to impose the desired lateral interface contact pressure between the insert 76 and the inner surface 74 of the borehole 68

[00075] When used as thimble anchors, the inserts 76 perform two functions, firstly that of providing an electrical conductor between the cast iron thimble 64, which is cast in-situ from molten iron around the non-embedded end of the thimble anchor 76, and the anode block 18. Secondly, because one end of the thimble anchor 76 protrudes from a surface of the anode block 18 into the stub hole 58, the thimble anchor 76 modifies the freeze profile of the cast iron thimble 64 by providing a heat sink on the inner wall of stub hole 58 which promotes the solidification or freezing of the iron across the full width of the space between the stub 48 outer surface and the inner wall of stub hole 58 at the locations of the

inserts 76, while there is molten metal above the insert 76 to fill in for the solidification shrinkage. This modified freeze profile will reduce or eliminate the usual shrinkage gap between the thimble 64 and the inner wall of stub hole 58 at those locations, thereby enabling a tighter contact and lower electrical resistance between the stub 48, thimble 64 and wall of stub hole 58 when the assembly 12 heats up in the reduction cell 10.

[00076] In the embodiments shown in Figures 8, 8a, 9 and 10, the inserts 76 are similar in appearance to nails, having a pointed end, a smooth shank and a single, enlarged head. It will be appreciated that the inserts 76 do not necessarily have this configuration, and that heads and pointed ends are not necessarily required. However, to enhance the function of the protruding portion of thimble anchor 76 as a heat sink, it is beneficial to provide the thimble anchor 76 with an enlarged head, as further discussed below. The thimble anchors 76 may, for example, have a single head or a duplex head.

[00077] Figure 8 is a sectioned view through a portion of anode block 18, showing the interior of one of the stub holes 58, and with the lower end of a stub 48 shown above the block 18. As shown, the anode electrode block 18 is provided with a plurality of impact driven, nail style thimble anchors 76 which, in this embodiment, are of cylindrical shape, and extend partially into the anode block 18 from a second surface thereof. In this embodiment, the second surface is the inner surface of the stub hole 58, comprising the flat bottom surface 60, the side surface 62, and/or in the helical grooves 66. Although only a single thimble anchor 76 may be required, improved results may be obtained by providing a plurality of thimble anchors 76. As shown in Figure 8a, a first end 78 of each thimble anchor 76 protrudes from the inner surface of the stub hole 58, and a second end 80 of each thimble anchor 76 is embedded in the inner surface of stub hole 58 with an interference fit. The protruding first end 78 of the thimble anchor 76 may have an enlarged head to enhance its function as a heat sink during the pouring and solidification of the molten metal in the gap between the stub hole 58 and stub 48, to form the thimble 64. It will be appreciated that the additional surface area

provided by the enlarged head at the first end 78 of thimble anchor 76 will provide an enhanced mechanical bond with the thimble 64, as well as an enhanced electrical connection with the thimble 64. Thus, with the provision of thimble anchors 76 as disclosed herein, better mechanical and electrical connections are formed between the stubs 48, the thimble 64, and the inner surface of stub hole 58.

[00078] Depending on the diameter and type of thimble anchor 76, it may be necessary to provide the inner surface of the stub hole 58 of Figure 8 with boreholes 68 corresponding in number to the thimble anchors 76, in order to achieve an interference fit with the desired amount of lateral interface contact pressure discussed above. This possibility is also illustrated in the close-up of Figure 8a, which shows one of the impact driven, nail style thimble anchors 76 of Figure 8 partially embedded in a pre-formed borehole 68 in the side surface 62 of the stub hole 58. The borehole 68 is pre-drilled in the substrate and has a first open end 70 at the second surface (i.e. the inner surface) of the anode block 18, and a second closed end 72 inside the anode block 18. The borehole 68 also has an inner wall 74, a width (in the case of the cylindrical bore 68, the same as diameter), and a length extending from the first end 70 to the second end 72 of bore 68. Except where the thimble anchor 76 is an expansion type anchor, the diameter of the borehole 68 is sized less than the diameter of the thimble anchor 76 in order to provide the desired lateral interface contact pressure between the thimble anchor 76 and the inner wall 74 of the borehole 68. As shown in Figure 8a, the first end 78 of thimble anchor 76 is proximate to the first end 70 of borehole 68 and spaced therefrom, while the second end 80 of thimble anchor 76 is received inside borehole 68 proximate to the second end 72 thereof. It can be seen from Figure 8a that the initial diameter of borehole 68, as shown at the second end 72 of borehole 68, is smaller than the diameter of the thimble anchor 76, the relative diameters of borehole 68 and thimble anchor 76 being selected to provide an interference fit having the desired amount of lateral interface contact pressure.

[00079] As shown, the thimble anchors 76 embedded partially in the bottom surface 60 of stub hole 58 may extend vertically downwardly from the bottom surface 60, although the thimble anchors 76 in bottom surface 60 may instead be sloped relative to the vertical. The partially embedded thimble anchors 76 in the side surface 62 may extend horizontally and radially outwardly from the side surface 62. Alternatively, the thimble anchors 76 in the side surface 62 may be sloped relative to the horizontal, extending downwardly and outwardly from the side surface 62, and one such sloped anchor 76 is shown in Figure 10.

[00080] In this embodiment, where the inserts 76 comprise thimble anchors, they will be formed of a material such as cast iron or carbon steel which can be recycled with the metal comprising the thimble 64.

[00081] The thimble anchors 76 provide the electrical connection between the thimble 64 and the anode block 18, while the cast iron thimble 64 will bond the anode block 18 to the stub 48. The thimble anchors 76 and stub 48 together create a good electrical connection through those components of the electrode assembly 12 even when it is cold. Further, the provision of at least one thimble anchor 76 in the bottom surface 60 of stub hole 58 with a cast iron bond will enable current distribution through the bottom surface 60 of the stub hole 58 through the stub 48. This typically does not occur when the stubs 48 sit directly on the bottom surface 60 of the stub hole 58 during iron pouring, which prevents a cast iron connection forming between the bottom of the stub 48 and the bottom surface 60 of stub hole 58.

[00082] Care must be taken if the thickness of the cast iron under the stub 48 is too great, thereby preventing the thimble stripping press from breaking and stripping the thimble 64 from the stub 48. To prevent this from happening, the bottom surface of the thimble 64 can be provided with a weaker breaking area. For example, as shown in Figure 9, the bottom surface 60 of stub hole 58 may be provided with one or more raised ridges 86 of carbon, extending wholly or partially across the diameter of bottom surface 60. The height of ridges 86 is below the tops

of the inserts 76 provided in the bottom surface 60, such that the ridges 86 will allow the cast iron 27 to flow over the ridges during casting to fill the space between the bottom surface 60 and the bottom of the stub 48 while creating the necessary weakness in that layer to enable the thimble stripping press to break and strip the cast iron metal lining 64 from the stub 48. The ridges 86 may be formed by altering the shape of the anode forming press mold by removing material from the bottom of the stub hole form in the shape and orientation suited to the needs of the thimble stripping press.

[00083] In another aspect, also shown in Figure 9a, only a portion of thimble 64 comprises a cast structure, and the remainder comprises a preform 82. The preform 82 is in the form of a circular disc, of the same material as the thimble 64, which is sized to fit inside the bottom of stub hole 58, against the bottom surface 60 thereof. The preform 82 becomes incorporated in the structure of the thimble 64 when the molten iron is cast, and helps to maintain a desired spacing between the bottom of stub 48 and the bottom surface 60 of stub hole 58. As shown in Figure 9a, the preform 82 may have apertures through which inserts 76 can be driven or threaded into the bottom surface 60 of stub hole 58. The preform 82 may be formed with grooves 84 on its lower or upper surface to allow the preform to be easily fractured when it is desired to remove the stub 48 and the thimble 64 from the stub hole 58 during anode recycling.

[00084] The preform 82 described above will typically be fastened to the bottom surface 60 of stub hole 58 after baking of the anode block 18. However, according to an alternate embodiment, the preform 82 may be inserted into the stub hole 58 while the anode block 18 is in a relatively soft, green state, in which case the preform 82 may be partially embedded in the bottom surface 60 of stub hole 58. In such an embodiment, the preform 82 may be formed into the anode block 18 during the anode forming process, i.e. at the time that the stub hole 58 is formed. Alternatively, the preform 82 may be inserted into the stub hole 58 after it is formed. Where the preform 82 is inserted into the green anode block 18, the inserts 76 may optionally be integrally formed with the preform 82.

[00085] Although Figures 8 to 10 illustrate the use of impact driven, nail style thimble anchors 76, other types of inserts 76 may be used in this embodiment, or in other embodiments described herein. For example, the inserts may be similar in appearance and/or function to conventional fasteners, such as friction fit or press fit nails, rods or spikes, screws or lag bolts, expansion anchors (including but not limited to lag shields, sleeve or wedge type expansion anchors, etc.), or other mechanically installed fasteners that produce a controlled lateral and/or axial pressure. For example, Figures 14a to 14c show three forms of inserts, labelled 76a, 76b and 76c. Insert 76a is in the form of a nail having a pointed tip, smooth shank and circular, enlarged head, similar to that shown in Figures 8 to 10. Insert 76b is in the form of a lag screw or lag bolt, having a hexagonal head, a pointed tip and a threaded shank. Figures 14a and 14b each shows insert 76a or 76b optionally being inserted into a pre-drilled bore 68 which is smaller in diameter than the shank of the insert 76a or 76b, the bore 68 being deformed radially outwardly by the insertion of insert 76a or 76b. However, it will be understood that the bores 68 are not always necessary, depending at least partly on the diameter of the insert 76a or 76b.

[00086] Insert 76c shown in Figure 14c is in the form of an expansion anchor having an inner threaded screw portion and an outer split sleeve portion. The insert 76c is initially inserted into a pre-drilled bore 68 with a relatively loose fit and, when the screw portion is threaded into the sleeve portion and tightened, the sleeve portion is forced outwardly against the inner wall 74 of bore 68 as the insert 76c, causing radially outward deformation of the bore 68.

[00087] Although the inserts 76 described and shown herein generally have cylindrical shanks, it will be appreciated that this is not necessary. Rather, the inserts may be of any convenient cross-section, including square-shaped, rectangular-shaped, star-shaped, fluted, etc.

[00088] In another embodiment now described with reference to Figures 6 and 7, the conductive metal inserts 76 are used to augment the existing cast iron

connected assemblies, by adding one or more additional electrical paths between the vertical conductor rod 38 and the anode block 18 using one or more electrically conductive bypass members, resulting in lower overall electrical resistance of the anode assembly 12.

[00089] The embodiment shown in Figures 6 and 7 includes a plurality of “external” electrically conductive bypass members 88, meaning that they form an electrically conductive connection from the vertical conductor rod 38 to the carbon material of the anode block 18, without forming a connection through the metal lining 64 of recess 58. Each of the bypass members 88 has a first end 90 connected to the vertical conductor rod 38 through an electrically conductive connection, and a second end 92 connected to the anode block 18 through an electrically conductive connection.

[00090] The anode block 18 is provided with a plurality of conductive metal inserts 76 in its top surface 42, forming an interference fit as defined above with the carbon material of the anode block 18. As discussed above, the inserts 76 are provided with or without bores 68, depending on the diameters of the inserts 76 and the strength of the substrate material.

[00091] The inserts 76 are at least partly received in the top surface 42. It can be seen from the drawings that the inserts 76 are located in top surface 42 such that the second ends 92 of the bypass members 88 are connected to the anode block 18 by at least one of the inserts 76. In the illustrated embodiment, each of the second ends is connected to the anode block 18 by two of the inserts 76. High pressure contact between the second ends 92 and the inserts 76 may be provided by using inserts 76 provided with compression washers 77 to maintain interface pressure, or using other conductive connections, including but not limited to brazing, welding or use of a nut 79 welded to the second end 92, or a locking thread 81 in the second end 92, ensuring an electrical connection with the insert 76. These latter two options are illustrated in Figures 14d and 14e, respectively.

[00092] It will be appreciated that the attachment of the bypass members 88 to inserts 76 also results in the second ends 92 of the bypass members 88 being secured to the top surface 42 of the anode block 18 with an electrically conductive connection.

[00093] The first ends 90 of the bypass members 88 are fastened to the vertical conductor rod 38 by means of fusion welding, soldering, brazing, interference fit fastener, screw, bolt, rivet, clamp or other mechanical or fusion connection which forms an electrical conduction path from the vertical conductor rod component 38 to the bypass member 88. In the embodiment of Figures 6 and 7, the first ends 90 of bypass members 88 are connected to the conductor rod 38 by mechanical fastening means 83a and 83b, including nuts and bolts, each pass through or adjacent to the conductor rod 38.

[00094] Although Figures 6 and 7 show bypass members having a specific configuration, it will be appreciated that the bypass members may instead comprise flexible conductors such as wire cables with lug ends for the attachment of the inserts 76.

[00095] According to another embodiment, the inserts 76 are used in combination with conductive connectors similar to the bypass members 88 described above, to replace and eliminate the conventional iron connection without, however, changing the main basis of the shapes of the electrodes, to allow a user to transition from traditional assemblies to the low resistance assemblies disclosed herein. Small changes to the shape of the carbon electrode block 18, 20 may be included in this embodiment to enable the use of the inserts 76, with or without bores 68.

[00096] Figures 11 and 12 illustrate an anode assembly 12 according to this embodiment, including a vertical conductor rod 38, yoke 50 and stubs 48 similar to those illustrated in the embodiments described above. However, in the present

embodiment, the lower end of each stub 48 is secured to the top surface 42 of the anode block 18 in an electrically conductive manner by a collar-shaped connector 94. Each connector 94 has a vertical sidewall 96 which receives the lower end of a stub 48. Because the stub 48 is cylindrical, the sidewall 96 in the illustrated embodiment of connector 94 is also cylindrical, and has an inside diameter slightly greater than the outside diameter of the stub 48, so as to closely receive the lower end of stub 48 in its hollow interior. The sidewall 96 is electrically connected to the stub 48 by welding, brazing or electrically conductive mechanical fasteners. It will be appreciated that the sidewall 96 may have any desired shape which provides an electrically conductive connection with the end of stub 48. Although the sidewall 96 is shown as being continuous, this is not necessarily the case. It will be appreciated that the sidewall 96 may instead be discontinuous, or comprise a plurality of separate pieces each attached mechanically and electrically to the stub 48.

[00097] The connector 94 also has at least one attachment portion 98 which is connected to the sidewall 96 in an electrically conductive manner, and may be integrally formed therewith. Each attachment portion 98 extends outwardly from the sidewall 96 of connector 94 and is secured and conductively connected to the top surface 42 of the anode block 18 by one or more conductive inserts 76, with or without a bore 68. High pressure contact between the connector 98 and the insert 76 may be provided by the same means described above with reference to Figures 6 and 7 and 14a to 14e, for example by using inserts 76 provided with compression washers 77, to maintain interface pressure, or using other conductive connections, including but not limited to brazing, welding or use of a backing plate, ensuring an electrical connection.

[00098] In the embodiment of Figures 11 and 12, the collar-shaped connector 94 includes a plurality of attachment portions 98, in the form of radially projecting tabs, each of which is secured to the top surface 42 by at least one insert 76. Each one of the attachment portions 98 includes means for permitting differential thermal expansion thereof in relation to the anode block 18. In the illustrated

embodiment, the means for permitting expansion comprise folds or bends 100 in the attachment portion 98, so as to permit the attachment portion 98 to expand, contract or flex in response to differential thermal expansion or contraction while supporting the load of the anode. Although bends 100 are shown as the means for permitting thermal expansion, other means may be used instead. For example, the attachment portions 98 may have expansion slits cut or formed into the attachment portion 98, providing a serpentine electrical path that enables different thermal expansion of the attachment portions 98 between inserts 76 relative to the thermal expansion of the top surface 42 of the anode block 18 between inserts 76.

[00099] As discussed above, the inserts 76 are used to connect components such as the collar-shaped connector 94 to the top surface 42 of the anode block 18, and also to conduct electricity into the block 18 through the inserts 76 themselves. The use of inserts 76 allows for modification of electrical resistance and current distribution through the anode assembly 12 by adjusting the material of inserts 76, as well as the length, diameter, contact surface area, quantity, location and interference fit or contact pressure between the insert 76 and the anode block 18. These adjustments may enable a more consistent electrical resistance from the vertical conductor rod 38 to any point on the bottom surface 22 of the block 18, which promotes consistent current density, lower overall electrical resistance, more consistent anode consumption resulting in a flatter bottom surface 22 of the block 18 during its operational life. The flatter anode bottom surface 22 may enable a higher portion of the block 18 to be consumed before it is necessary to remove the anode 12 from operation, thus reducing recycle volumes and reducing the ongoing replacement costs of anode replacement.

[000100] The use of inserts 76, with or without bores 68, may also be applied in a cathode assembly 14, between the cathode block 20 and the current collector bar 52. The collector bar 52 is typically bonded to the cathode block 20 by a layer of cast iron 57 between the collector bar 52 and the corresponding recess 56 (also referred to in this embodiment as "slot 56"), in the bottom surface 54 of carbon cathode collector block 20. The current collector bar 52 is bonded to the carbon

cathode collector block 20 with molten cast iron 27 while it is upside down (See Fig. 15) prior to assembly into the reduction cell 10. Bonding may instead be done using a carbon adhesive paste. The following embodiments apply to both cast iron and carbon adhesive collector bar connections.

[000101] As will be appreciated, there may be multiple current collector bars 52 connected to each cathode block 20. Each block 20 is installed across the width of the reduction cell 10 and multiple blocks 20 are installed beside each other to line the bottom floor of the reduction cell 10. As shown in Figures 15 and 16, the current collector bar 52 has a flat bottom surface 53 which is substantially coplanar with the bottom surface 54 of the cathode block 20.

[000102] In accordance with an embodiment shown in Figures 17 to 19, there may be provided one or more electrically conductive metal connectors 112 in the form of a flat, elongated strap which is attached to the bottom surface 54 of carbon cathode collector block 20 by inserts 76, with or without bores 68. The inserts 76 are received in the bottom surface 54, adjacent to slot 56. Each strap connector 112 extends substantially transversely across the bottom surface 54, extending across the slot 56 and having each of its ends secured to the bottom surface 54 by at least one insert 76. The middle portion of each strap connector 112 is electrically connected to the current collector bar 52 by means of fusion weld, solder, braze, friction fit pin, screw, bolt or other mechanical or fusion connection which forms an electrical conduction path from the collector bar 52 to the strap connector 112. The strap connectors 112 of Figure 17 are connected to the bottom surface 53 of each collector bar 52 by a fusion connection, whereas Figure 19 shows a variant in which mechanical connections are formed between the strap connectors and collector bar 52. If protrusion of strap connector 112 below the plane of bottom surface 54 is undesirable, it is possible to machine grooves 114 (Figure 19) or clearance cavities into the bottom surface 54 of the cathode block 20 to provide the necessary clearance.

[000103] Although the strap connectors 112 are shown in Figure 17 as extending across both sides of the slot 58, this is not necessarily the case. Rather, as shown in Figure 19, the strap connectors 112 may be shorter pieces, having one end electrically connected by an insert 76 to the bottom surface of cathode block 20 and the other end electrically connected to the collector bar 52. For example, Figure 19 shows an insert 76 in the form of a bolt with a lock washer 77 compressed between the bolt head and one end of the strap connector 112. The other end of strap connector 112 is bolted to the bottom surface 53 of the current collector bar 52 by a bolt and washer, which are similarly labelled 76 and 77, but which are not necessarily the same as the insert 76 and lock washer 77.

[000104] Alternately, as shown in Figure 20, the connectors 112 may be comprised of flexible electrical conductors such as wire cable 113 with lugs 115 at one or both ends thereof, to attach to the inserts 76. A small amount of extra wire cable 113 may be provided to allow for differential expansion between the collector bar 52 and the cathode block 20.

[000105] It will be appreciated that the use of strap connector 112 allows the layer 57 of cast iron or carbon paste to be bypassed or eliminated, as the strap connector provides a direct, electrically conductive connection between the current collector bar 52 and the bottom surface 54 of the cathode block 20. As shown in Figure 17, a plurality of spaced strap connectors 112 may be provided along the length of block 20, each secured by inserts 76, so as to provide multiple electrical connections between the block 20 and the current collector bar 52. This provides an improved current distribution across the length and the width of the block 20.

[000106] As with the anode assemblies discussed above, the use of inserts 76 allows modification of the electrical resistance and current distribution of the cathode assembly 14 from the end of the collector bar 52, where it exits the reduction cell 10, to the top surface 30 of the cathode block 20, by adjusting the insert material, length, diameter, quantity, position and interference fit or contact

pressure relative to the carbon material of the cathode block 20. For example, the current distribution and resistance profile of the cathode assembly 14 may be made more even across the top surface 30 by using longer or more inserts 76 towards the centre of block 20, in relation to its ends as illustrated in Figure 18. The actual lengths and positions of the inserts 76 may be determined during cathode assembly outside of the reduction cell 10, using a suitable ohmmeter to measure the resistance from the top surface 30 to the end of the collector bar 52. These modifications promote consistent current density, lower overall electrical resistance, more even cathode wear, a longer cathode life, and a flatter cathode top surface 30 during its operational life.

[000107] Due to differential thermal expansion of the current collector bar 52 it is also desirable to provide strap connectors 112 with means for permitting differential thermal expansion. As shown in Figures 18 and 19, the means for permitting expansion comprise folds or corrugations 100 in the connector 112, so as to provide a bellows-like arrangement which can expand or contract in response to differential thermal expansion or contraction.

[000108] It is appreciated that the strap connectors 112 may not be limited to singular pieces of conductor but may be comprised of multiple layers of thin straps which flex more easily than solid pieces while providing a similar electrical resistance. For example, the strap connectors 112 in Figure 19 are shown as comprising two layers 117.

[000109] According to another embodiment, illustrated in Figure 13, a low resistance yoke assembly 126 is provided for forming a connection between the lower end of a vertical conductor rod 38 and the top surface 42 of an anode block 18.

[000110] The yoke assembly 126 comprises a pair of curved metal struts 128, which may be identical to one another. Each of the struts has an upper end 130 and an opposed lower end 132. The upper end 130 of each strut 128 is bonded

through mechanically and electrically conducting attachment to opposing side surfaces of the lower end of the vertical conductor rod 38, which is shown as having a rectangular cross section with four vertical side surfaces. The mating surface of the struts 128 and the rod 38 may be electroplated, or bonded with suitable surface material to enable subsequent bonding of the strut 128 to the rod 38 by welding, brazing or other electrical connection. Following attachment of the struts 128 to the rod 38, one or more mechanical through fasteners 136, such as but not limited to bolts with washers and nuts, are inserted through the struts 128 and rod 38, and are adequately tightened to remove cyclical physical stress on the electrical joint due to loading and unloading the weight of suspended anode block 18 from the rod 38.

[000111] The two struts 128 are arranged in opposed, face-to-face relation with each other. In this embodiment they are joined together by one curved connector or brace 134, which contributes to the mechanical strength of the struts 128 while enabling some flexure of the struts 128 under thermal expansion stress. The struts 128 may be made of a single alloy of metal or clad or cored with different conductive metal.

[000112] The lower ends 132 of the struts 128 are curved outwardly away from the vertical conductor rod 38 and may be formed with multiple sections, separated by slits 138. The lower ends 132 mate with the top surface 42 of the anode block 18, and for this purpose the lower ends 132 are provided with one or more holes to enable the installation of one or more inserts 76 through the lower ends 132 and into the top surface 42 of the anode block 18, with or without bores 68. The inserts 76 therefore carry the weight of the anode block 18 from the struts 128 and provide an electrical connection from the vertical conductor rod 38 to the anode block 18. To provide added resistance against withdrawal of the inserts 76, at least some of the bores 68 may be angled from the vertical, toward the vertical conductor rod 38, so that the inserts 76 received in these bores 68 will be "toed in" toward one another. Other inserts 76 may be angled from the vertical in other directions to provide improved current distribution within the anode block 18. If, as

shown in Figure 13, multiple holes are provided within the same section of strut 128, such that one section is secured by two or more inserts 76, then an expansion fold 101 is provided in between the holes and inserts 76 to enable differential expansion of the strut 128 versus the anode block 18, with minimal stress imposed on the anode block 18 due to the flexing of the curved struts 128.

[000113] It is appreciated that the lower ends 132 of the struts 128 may be connected to the vertical conductor rod 38 by other means than mechanical fasteners 136, provided that electrical conduction is maintained between the two parts during operation.

[000114] As compared to the traditional rod assembly, the configuration of the low resistance yoke assembly 126 eliminates one fusion weld on the bimetallic transition joint, increases the electrical contact surface area of the strut 128 to rod 38 connection through connection on both sides of the rod 38, it removes the physical stresses in the bimetallic connection from the weight of the suspended load by use of the through bolt connections, it eliminates the yoke to stub welded connection, it eliminates the condition of stub toe-in that the traditional yoke & stub assembly suffers due to repeated thermal stress and material creep at high temperatures, it enables the use of inserts 76 with toed in orientation to carry high loads through the cross section of the inserts 76. These benefits provide a low electrical resistance configuration with long life.

[000115] According to convention, the upper end 44 of the aluminum or copper vertical conductor rod 38 is temporarily attached to anode buss bar 46 with a buss clamp (not shown). The electrical resistance through the mating surface(s) of the rod 38 and buss 46 is dependent on the cleanliness, surface area and clamp pressure between the mating surfaces. Over repeated use the surfaces of the rod 38 and buss 46 may become oxidized or pitted from arcing which introduces surface roughness and a surface oxide layer of relatively high electrical resistance. The electrical resistance of the rod 38 to buss 46 connection may be reduced by cladding or electroplating the mating surface 140 of the buss 46 (Figure 11) and/or

the mating surface 142 of rod 38 (Figure 11) with an electrically conductive corrosion resistant metal such as, but not limited to, nickel, platinum or gold. Although this surface treatment may add a small amount of electrical resistance compared to a clean metal interface (aluminum rod to aluminum bus or copper rod to aluminum bus) this clad or electroplated surface will maintain its electrical resistance at levels less than those of oxidized aluminum or oxidized copper over the life of the rod assembly.

[000116] One or both ends of each steel current collector bar 52 are connected by a bolted connection to the cathode buss 24 flex connectors (not shown). Also, a portion of each collector bar 52 is in electrical contact with the cathode block 20 through the cast iron layer 57, as explained above with reference to Figure 3. The mating surface(s) of collector bar 52 which are in electrical contact with the cast iron layer 57 may oxidize and develop an electrically resistant oxide layer due to the high temperature of the collector bar during operation. Similarly, the mating surface(s) of collector bar 52 which are in contact with the flex connectors of the cathode buss 24 may develop oxidation. For this reason, the mating surface(s) of the current collector bar 52 which are in contact with the cathode buss flex connectors and/or the cast iron layer 57 be clad or electroplated with electrically conductive corrosion resistant material, such as any of the electrically conductive corrosion resistant metals mentioned above.

[000117] Figure 21 shows a section of a current collector bar 52 in which a cladding 141 of the electrically conductive corrosion resistant metal is provided on all four surfaces of the bar 52. Alternatively, the cladding 141 may be applied only to the mating surfaces which are in contact with the cast iron layer 57 or the cathode buss 24. The cladding may have a thickness of about 1 mm. Alternatively, the current collector bar 52 may be electroplated with a coating of the electrically conductive corrosion resistant metal, the coating having a thickness on the order of about 0.1 mm.

[000118] The embodiments of illustrations in Figures 22 to 26 relate to reducing electrical resistance between the current collector bar 52, the cast iron layer 57 and the carbon of the cathode block 20. The means for reducing electrical resistance in the cathode 14 are similar to the means for reducing electrical resistance in the anode 12, discussed above, using conductive inserts 76. However, some differences are necessitated by the fact that the thermal expansion of stubs 48 and thimbles 64 in the anode 12 is primarily radial without relative movement between the components, whereas the thermal expansion of the collector bar 52 and cast iron layer 57 in the cathode 14 is primarily axial and with relative movement between the components due to different coefficients of thermal expansion.

[000119] Figure 22 is a partial, cross-sectional view of a cathode assembly 14, showing the cathode block 20 having a slot 56 in its bottom surface 54, with a cast iron layer 57 and current collector bar 52 received in the slot 56. As shown, the interior surfaces of slot 56 are provided with a plurality of conductive inserts 76 which are received in the carbon of cathode block 20 with an interference fit, as discussed above with reference to the anode 12. The above discussion of the embedding of inserts 76 into the anode block 18 applies equally to the present embodiments, except where otherwise discussed below.

[000120] The conductive inserts 76 embedded in the surfaces of slot 56 do not significantly protrude into the cast iron layer 57. Rather, the heads of inserts 76 in Figures 24 and 25 are intended to be flat, optionally having rounded edges, so as to permit axial expansion movement of the cast iron layer 57 relative to the cathode block 20. It will be appreciated that embedment of the heads of inserts 76 in the cast iron layer 57 could result in damage to the carbon material when the cast iron layer expands axially relative to the cathode block 20. Furthermore, to prevent a bond forming between the inserts 76 and the cast iron layer 57, the heads of inserts may be provided with a thin coating of graphite powder, or other electrically conductive non-stick material which will not significantly increase electrical resistance between the inserts 76 and the cast iron layer 57.

[000121] As shown in Figure 22, a conductive metal slot liner 144 may be provided between the cast iron layer 57 and the interior surfaces of slot 56. The conductive slot liner comprises a thin sheet of metal through which the inserts 76 extend into the cathode block 20, the heads of the inserts 76 holding the liner in place as shown in Figure 26b. As shown in Figure 23, the liner 144 may have expansion slits 146 between the insert locations, shown as holes 148, to allow for differential thermal expansion of the liner 144 relative to the cathode block 20. The liner 144 may alternately be comprised of a plurality of close fitting or overlapping plates of conductive metal with each piece attached to the inside surface of the cathode slot 56 by means of at least one insert 76. It will be appreciated that the provision of liner 144 may improve current distribution through the cathode block 20 by improving the electrical connection between the cast iron layer 57 and the surface of the cathode slot 56.

[000122] Instead of using a liner, the current distribution may be enhanced by providing more inserts 76 or, as shown in Figure 24, by providing the inserts 76 with larger heads and/or conductive metallic washers 150. For example, inserts 76 with enlarged heads 78 having rounded edges 78, which may be partially embedded in the carbon of block 20, are shown in Figure 25, which will be discussed below.

[000123] In the case of the anode 12, the inserts 76 embedded in the anode block 18 have heads which protrude into the stub hole 58 and are embedded in the thimble 64, to modify the shape of the freezing iron to reduce shrinkage gap between the cast iron and the stub hole wall. This reduces the electrical resistance between those components. As shown in Figure 25, this effect can be attained in the cathode 14 by providing one or more conductive collector bar anchors 152, the collector bar anchors 152 having one end attached to the collector bar 52 and another end protruding into the slot 56. The ends of the collector bar anchors 152 protruding into slot 56 will become embedded in the cast iron layer 57 and provide heat sinks during casting of layer 57. This will reduce the solidification shrinkage gap local to the collector bar anchors, between the cast iron layer 57 and the inner

surfaces of slot 56 for the same reasons as discussed above, by modifying the freeze profile of the cast iron layer 57 to promote solidification of the iron across the full width of the space between the collector bar 52 and the cathode block 20, as illustrated by the freeze isotherms 29 in Figure 26. This provides a "tighter" fit of the collector bar 52 and the cast iron layer 57 within the cathode slot 56, thereby reducing electrical resistance between the cathode block 20, the collector bar 52 and the cast iron layer 57.

[000124] The quantity, depth, dimensions and locations of the collector bar anchors 152 may be modified to adjust the electrical resistance between the top surface 30 of the cathode block 20 and the collector bar 52 in order to make the electrical resistance as consistent as possible. In order to enhance the heat sink effect, the collector bar anchors 152 may be provided with enlarged heads, as shown in Figure 25. Also, the anchors 152 and the holes 154 in which they are received may be threaded, to permit the amount of protrusion of the anchor 152 to be adjusted. For example, the degree of protrusion can be adjusted so that the heads of the anchors 152 contact the heads of the conductive inserts 76 embedded in the cathode block 20. This will further improve the electrical connection between collector bar 52 and cathode block 20.

[000125] Figure 26 illustrates a cathode assembly 14 according to a variant of the embodiment shown in Figure 25. The cathode assembly of Figure 26 includes inserts 76 having enlarged, rounded heads 78 which are impact driven into the carbon of cathode block 20, rather than being driven into pre-formed bores 68. The right hand side of current collector bar 52 is provided with threaded collector bar anchors 152 adjustably received in threaded holes 154, the collector bar anchors 152 being in the form of threaded studs or rods, not having enlarged heads, the protruding ends optionally being tapered. The protruding ends of the collector bar anchors 152 may or may not be in contact with the heads 78 of inserts 76.

[000126] The left hand side of current collector bar 52 is provided with fixed collector bar anchors 156 which are secured to the outer surface of current collector bar by fusion bonding, such as by welding, brazing or soldering. The fixed anchors 156 may be in the form of cylindrical studs or rods, and the protruding ends may be tapered as shown. The fixed anchors 156 will act as heat sinks, and have a similar effect on the freeze profile of the cast iron layer 57, as indicated by the freeze isotherms 29 on the left hand side of Figure 26.

[000127] Figures 27 and 28 show an alternate embodiment of a cathode assembly 14 in which no cast iron layer 57 is provided in the space between the current collector bar 52 and the cathode block 20. The cathode block 20 is conductively connected to the collector bar by a strap connector 112 comprising a wire cable 113 with lugs 115, one of the lug ends 115 being conductively connected to the bottom surface 54 of cathode block 20 by a conductive insert 76, the opposite lug end 115 being conductively connected to the bottom surface 53 of collector bar 52 by a bolt 176. Alternatively, a plurality of any of the strap connectors 112 described above may be provided.

[000128] In the embodiment of Figures 27 and 28, the current collector bar 52 is held in place by one or more conductive hanger assemblies 160, one of which is shown in the drawings, comprising a tongue portion 162 and a slot portion 164, the tongue portion 162 being slidably received in the slot portion 164 along the longitudinal axis of the collector bar 52, as best seen in the cross-sectional side elevation of Figure 29. In the illustrated embodiment, the tongue portion 162 has an attachment flange 166 which is secured to the top surface of collector bar 52 (opposite the bottom surface 53) by one or more bolts 176, although other mechanical or fusion connections may be used instead. The slot portion has a pair of attachment flanges 168 along its lateral edges, the flanges being attached to the inner surface of slot 56 by conductive inserts 76 inserted in the carbon of cathode block 20. It will be appreciated that the positions of the tongue portion 162 and slot portion 164 could be reversed, i.e. with the slot portion 164 attached to collector bar 52 and the tongue portion 162 attached to the cathode block 20.

[000129] With the conductive hanger assembly 160, relative thermal expansion of the collector bar 52 and the cathode block 20 results in axial longitudinal movement of the tongue portion 162 within slot portion 164, thereby providing support for the collector bar 52 while avoiding the creation of thermal stresses.

[000130] If eliminating the layer 57 of cast iron or paste the gap remaining between the collector bar 52 and the inner surface of the cathode slot 56 may be filled with thermal insulation to reduce heat transfer between the cathode block 20 and the collector bar 52.

[000131] Although specific embodiments have been described herein, the claims are not limited to these embodiments. Rather, the disclosure includes all embodiments which may fall within the scope of the following claims.

What is claimed is:

1. An electrode assembly for use in a reduction cell for the production of metal, the electrode assembly comprising:
 - (a) an electrically conductive carbon electrode block having a first surface and a second surface, wherein the first surface faces an interior of the reduction cell when the electrode assembly is in use;
 - (b) an electrically conductive metal member having a first end and a second end, wherein the first end of the metal member is connected to the carbon electrode block in an electrically conductive manner, and the second end of the metal member is adapted for connection to a buss bar in an electrically conductive manner;
 - (c) a solid, conductive metal insert at least partly received in the carbon electrode block, wherein the insert extends into the carbon electrode block from the second surface thereof; andwherein the metal insert is received in the carbon electrode block with an interference fit, such that the insert exerts a lateral force on the carbon electrode block.
2. The electrode assembly of claim 1, wherein the electrode is a pre-baked carbon anode, wherein the first surface of the carbon electrode block is a bottom surface thereof, and wherein the electrically conductive metal member comprises a vertical conductor rod.
3. The electrode assembly of claim 2, wherein the electrically conductive metal member further comprises a vertical stub at its first end, the carbon electrode block has a top surface opposite the bottom surface, a recess is formed in the top surface, with an end of the vertical stub being received in the recess.
4. The electrode assembly of claim 3, wherein the second surface in which the insert extends comprises an inner surface of the recess, the inner surface being selected from a bottom surface and a side surface of the recess.

5. The electrode assembly of claim 4, wherein the insert extends into the bottom surface of the recess and extends vertically downwardly therefrom.
6. The electrode assembly of claim 4, wherein the insert extends into the side surface of the recess and extends radially outwardly therefrom.
7. The electrode assembly of claim 4, wherein the insert is inclined downwardly and outwardly from said second surface.
8. The electrode assembly of any one of claims 4 to 7, comprising a plurality of said inserts provided in the bottom surface and/or the side surface of the recess, with each of said inserts being at least partly received in the carbon electrode block.
9. The electrode assembly of claim 8, wherein a portion of each of said inserts protrudes from the bottom surface or the side surface of the recess.
10. The electrode assembly of claim 9, wherein the portion of each insert which protrudes from the bottom surface or the side surface includes an enlarged head.
11. The electrode assembly of any one of claims 4 to 10, wherein the recess is provided with a conductive metal lining through which an electrically conductive connection is formed between the stub and the carbon electrode block, and wherein the insert or the plurality of inserts is in direct, electrically conductive contact with the conductive metal lining of the recess.
12. The electrode assembly of claim 11, wherein at least a portion of the conductive metal lining comprises a cast portion which is formed in situ between the stub and the carbon electrode block.
13. The electrode assembly of claim 12, wherein a portion of the conductive metal lining comprises a solid preform which is combined with the cast portion

during formation of the metal lining, and wherein the insert or the plurality of inserts is in direct, electrically conductive contact with the preform prior to formation of the cast portion.

14. The electrode assembly of claim 13, wherein the preform comprises a bottom plate which is in contact with a bottom surface of the recess.

15. The electrode assembly of claim 3, wherein the electrode assembly further comprises a plurality of said vertical stubs at its first end, the stubs being spaced apart from one another, and the carbon electrode block has a plurality of said recesses formed in its top surface, with an end of each of the vertical stubs being received in a corresponding one of the recesses; and

wherein each of the vertical stubs is secured to the vertical conductor rod through an electrically conductive metal yoke.

16. The electrode assembly of claim 15, wherein the electrode assembly further comprises a plurality of electrically conductive bypass members, each of which bypasses the yoke and one of the vertical stubs, wherein each of the bypass members has a first end connected to the vertical conductor rod through an electrically conductive connection, and a second end connected to the carbon electrode block through an electrically conductive connection.

17. The electrode assembly of claim 16, wherein the carbon electrode block is provided with a plurality of said inserts in the top surface thereof, and wherein the second end of each of the bypass members is connected to at least one of the inserts.

18. The electrode assembly of claim 17, wherein the second end of each of the bypass members is secured to the top surface of the electrode by at least one of the inserts, and wherein the second end of each bypass member includes an expandable or flexible portion.

19. The electrode assembly of claim 2, wherein the carbon electrode block has a top surface opposite the bottom surface, and is provided with a plurality of said inserts in the top surface thereof,

wherein the electrode assembly further comprises a collar-shaped connector having a side wall to receive the first end of the electrically conductive metal member and to provide an electrically conductive connection between the electrically conductive metal member and the carbon electrode block, and

wherein the collar-shaped connector further comprises at least one attachment portion which is connected to the side wall and extends outwardly therefrom, each of the attachment portions being connected to at least one of the inserts to provide an electrically conductive connection between the attachment portion and the at least one of said inserts.

20. The electrode assembly of claim 19, wherein the plurality of said inserts is distributed across the top surface of the carbon electrode block, and wherein the at least one attachment portion is connected to each of the inserts.

21. The electrode assembly of claim 20, wherein the electrically conductive metal member further comprises a vertical stub at its first end, wherein each of the vertical stubs is secured to the vertical conductor rod through an electrically conductive metal yoke;

wherein the electrode assembly further comprises a plurality of said collar-shaped connectors, and the sidewall of each collar-shaped connector receiving an end of one of the vertical stubs; and

wherein each of the at least one attachment portions is conductively connected to all of the vertical stubs through the collar-shaped connectors.

22. The electrode assembly of claim 2, wherein the carbon electrode block has a top surface opposite the bottom surface, and is provided with a plurality of said inserts in the top surface thereof,

wherein the electrode assembly further comprises a yoke assembly through which an electrically conductive connection is provided between the electrically conductive metal member and the carbon electrode block;

wherein the yoke assembly comprises a plurality of curved metal struts, each having an upper end and an opposed lower end, the upper end being secured by an electrically conductive connection to the lower end of the electrically conductive metal member, the lower end being secured to the carbon electrode block with an electrically conductive connection by at least one of said inserts.

23. The electrode assembly of claim 22, wherein the lower ends of the struts extend outwardly away from one another and from the electrically conductive metal member.

24. The electrode assembly of claim 22 or 23, wherein the yoke assembly includes a pair of said struts, oppositely disposed relative to one another.

25. The electrode assembly of claim 1, wherein the electrode is a pre-baked carbon cathode, wherein the first surface of the carbon electrode block is a top surface thereof and the carbon electrode block has a bottom surface opposite the top surface, and wherein the electrically conductive metal member comprises a current collector bar having an end received in a slot in the bottom surface, the current collector bar and the bottom surface being substantially parallel.

26. The electrode assembly of claim 25, wherein a cast iron layer is provided in the slot, between the current collector bar and the carbon electrode block.

27. The electrode assembly of claim 26, wherein the second surface in which the insert extends comprises an inner surface of the slot, the inner surface of the slot being selected from a top surface and a side surface of the slot.

28. The electrode assembly of claim 27, wherein the insert has a flat head which is received between the cast iron layer and the carbon electrode block.

29. The electrode assembly of claim 28, further comprising a conductive metal liner and/or a conductive metal washer received between the flat head of the insert and the carbon electrode block.

30. The electrode assembly of claim 26, wherein the current collector bar is provided with one or more collector bar anchors, each said anchor having a first end attached to the collector bar and a second end embedded in the cast iron layer.

31. The electrode assembly of claim 30, wherein the first end of each said anchor comprises a threaded shank which is received in a threaded bore in the collector bar.

32. The electrode assembly of claim 25, wherein the second surface in which the insert is received comprises the bottom surface of the carbon electrode block, and wherein the current collector bar has a flat bottom surface which is substantially coplanar with the bottom surface of the carbon electrode block.

33. The electrode assembly of claim 32, wherein an electrically conductive metal connector is attached to the bottom surface of the carbon electrode block and to the flat bottom surface of the current collector bar, to provide an electrically conductive connection between the current collector bar and the carbon electrode block.

34. The electrode assembly of claim 33, wherein the electrically conductive metal connector is attached to the top surface of the carbon electrode block by said insert, and is in electrically conductive contact with said insert.

35. The electrode assembly of claim 34, wherein the electrically conductive metal connector is in the form of one or more layers of flat metal strap.

36. The electrode assembly of claim 35, wherein the strap has an expandable portion to permit deformation of the electrically conductive metal connector in

response to differential thermal expansion of the current collector bar and the carbon electrode block, along an axis defined by the current collector bar.

37. The electrode assembly of claim 34, wherein the electrically conductive metal connector comprises a flexible cable connector.

38. The electrode assembly of claim 37, wherein the flexible cable connector is provided with lug ends.

39. The electrode assembly of any one of claims 32 to 38, wherein the electrode assembly comprises a plurality of said inserts provided in the bottom surface of the carbon electrode block, with each of said inserts being at least partly received in the carbon electrode block, and wherein the electrode assembly further comprises a plurality of said electrically conductive metal connectors, each providing an electrically conductive connection between the current collector bar and at least one of the inserts.

40. The electrode assembly of claim 39, wherein the inserts are spaced apart along a length of the carbon electrode block.

41. The electrode assembly of claim 39, wherein the inserts are of different dimension to control the resistance of the top surface of the carbon block relative to the external portion of the collector bar.

42. The electrode assembly of any one of claims 1 to 41, wherein a thickness of the insert and the width of the bore are sized relative to one another such that an interface contact pressure between the insert and the adjoining carbon electrode block is at least about 1 kPa.

43. The electrode assembly of claim 42, wherein the interface contact pressure is less than about 10 MPa.

44. The electrode assembly of claim 43, wherein the interface contact pressure is between about 1 MPa and about 10 MPa.

45. The electrode assembly of claim 42, wherein a maximum interface contact pressure is less than about one half of the breaking pressure required to break the surrounding carbon electrode block.

46. The electrode assembly of any one of claims 1 to 45, wherein the second end of the metal member, which is adapted for connection to the buss bar, includes a connecting surface which is adapted to mate with the buss bar, and wherein the connecting surface is electroplated or clad with corrosion resistant conductive material.

47. The electrode assembly of any one of claims 1 to 46, wherein said insert is received in a bore either pre-drilled or formed in the carbon electrode block.

48. The electrode assembly of any one of claims 1 to 47, wherein the electrode is pre-baked and the insert is inserted into the carbon electrode block either before or after the electrode is pre-baked.

49. The electrode assembly of any one of claims 25 and 32 to 38, wherein the current collector bar is supported within the slot of the carbon electrode block by at least one hanger assembly comprising a tongue portion slidably received in a slot portion.

50. The electrode assembly of claim 49, wherein the slot portion is secured to the carbon electrode block by one or more of said conductive metal inserts, and the tongue portion is secured to the current collector bar.

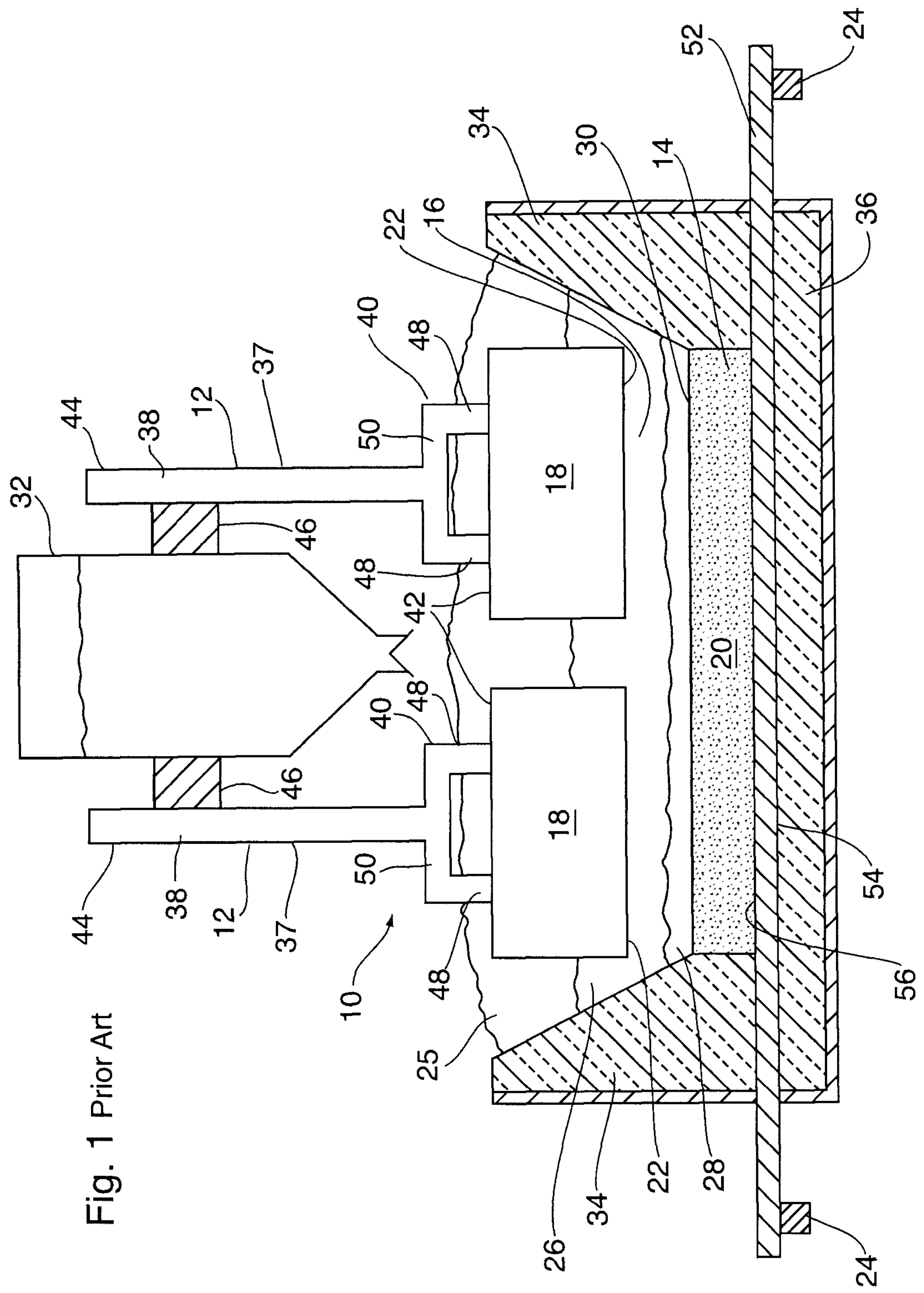


Fig. 1 Prior Art

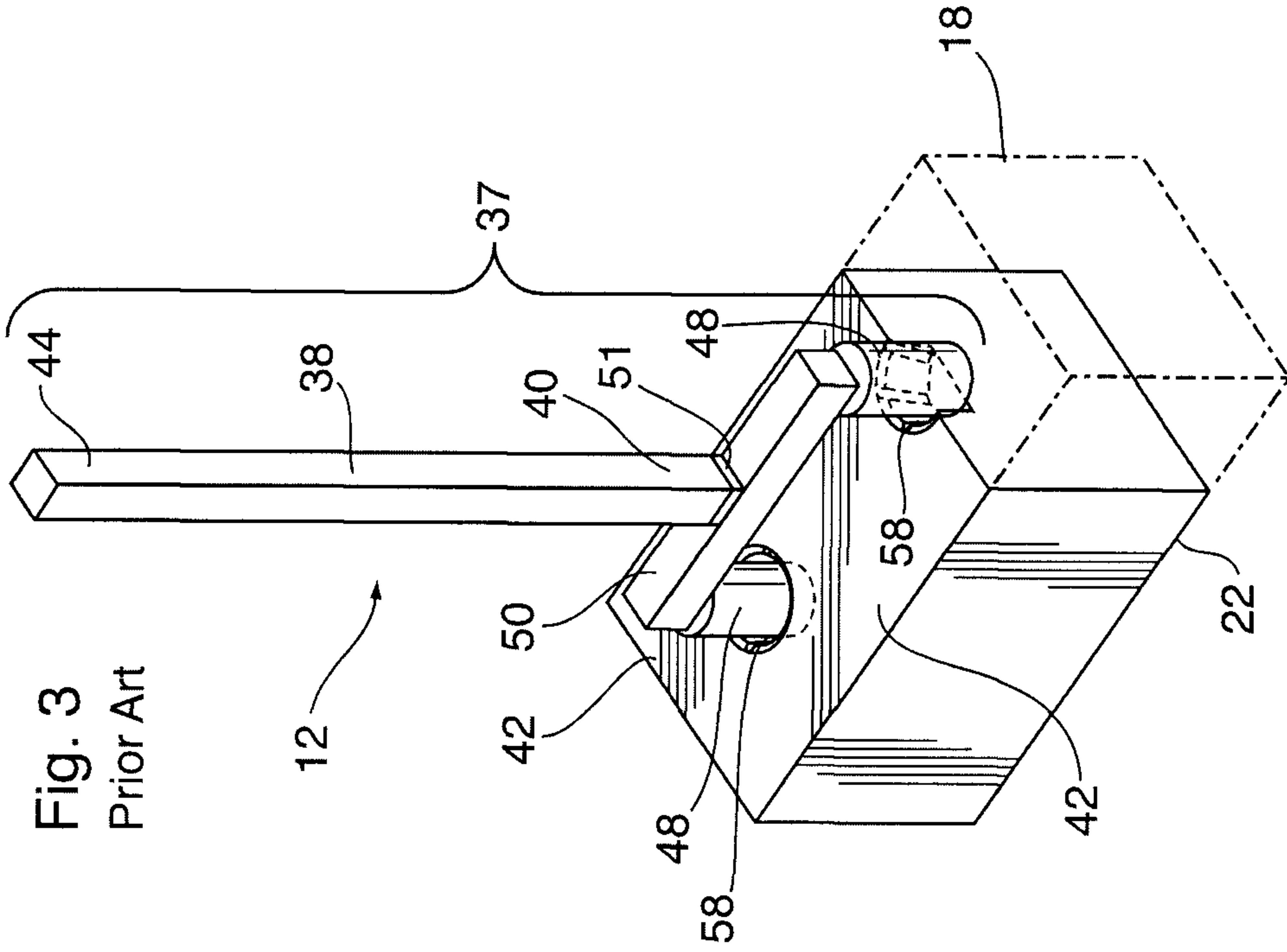
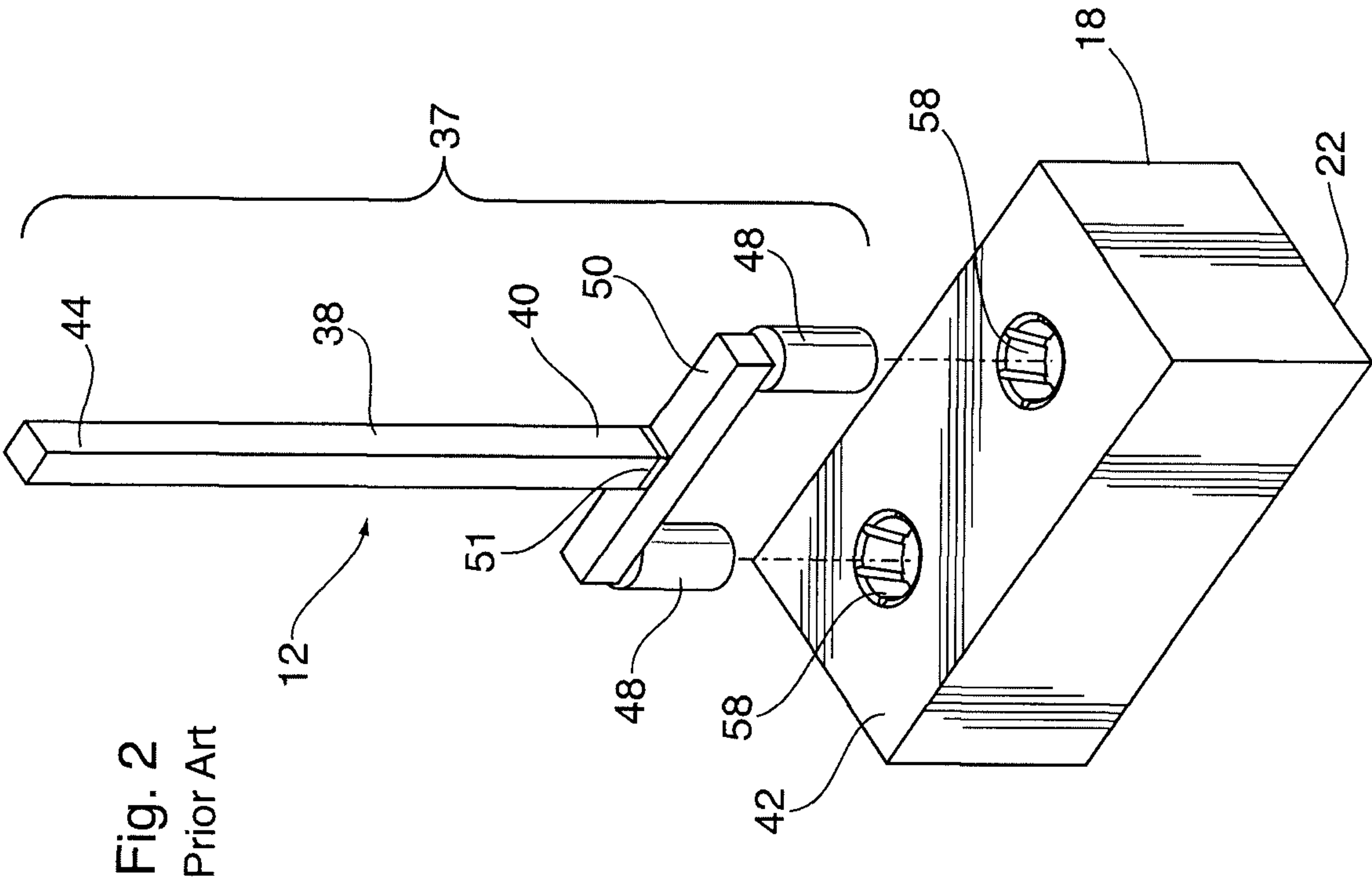


Fig.4 Prior Art

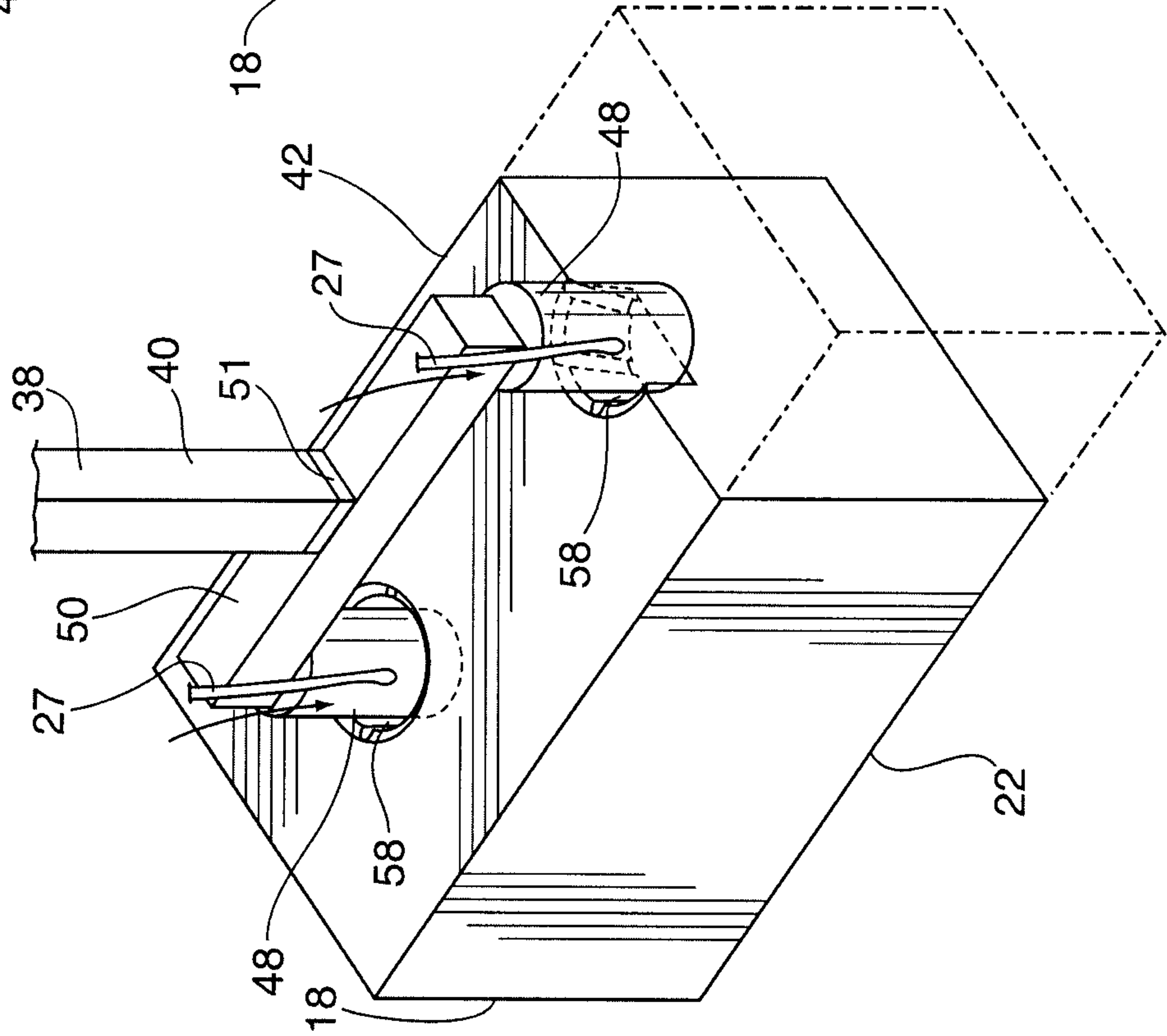


Fig.5 Prior Art

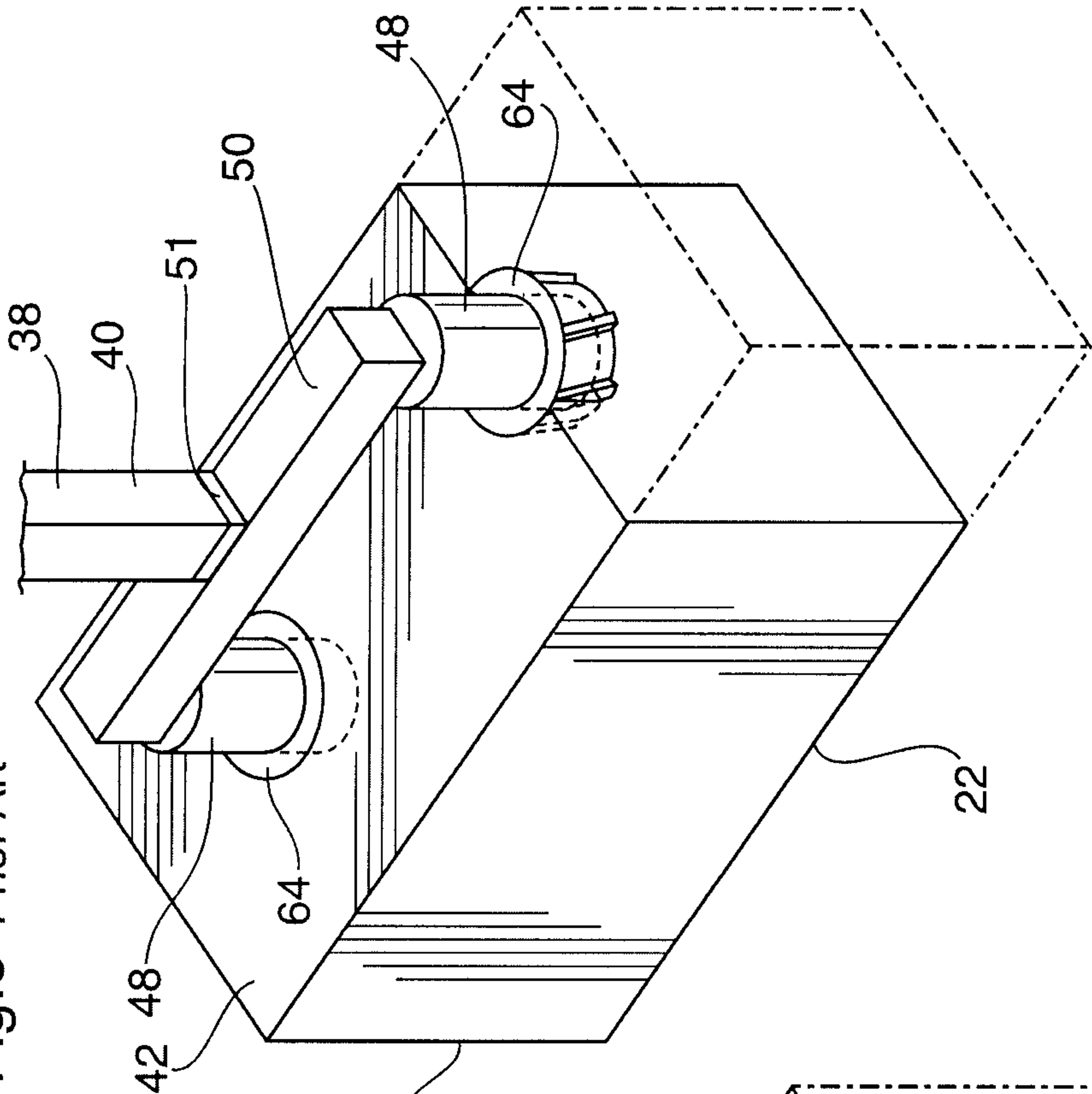
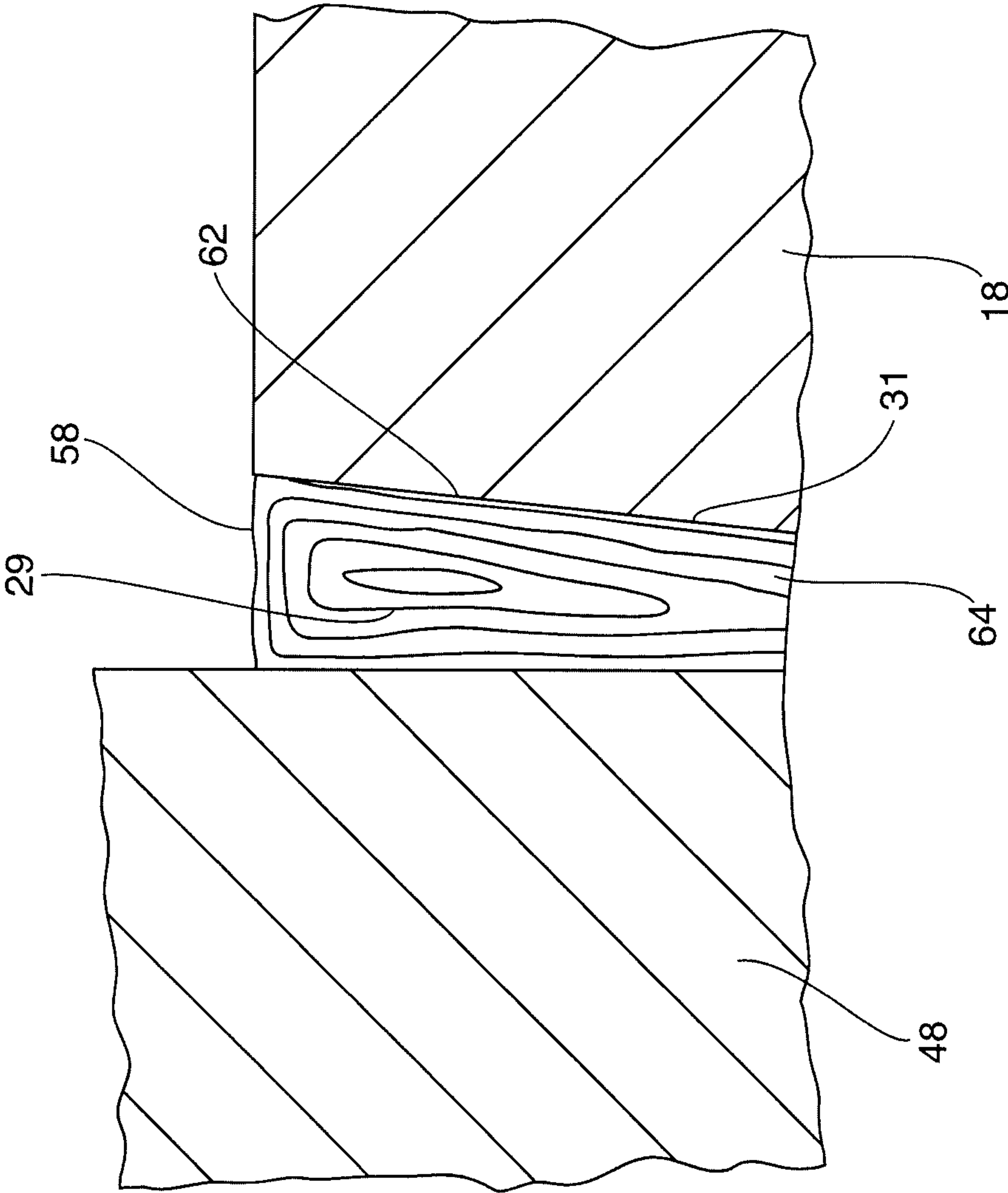


Fig.5a Prior Art



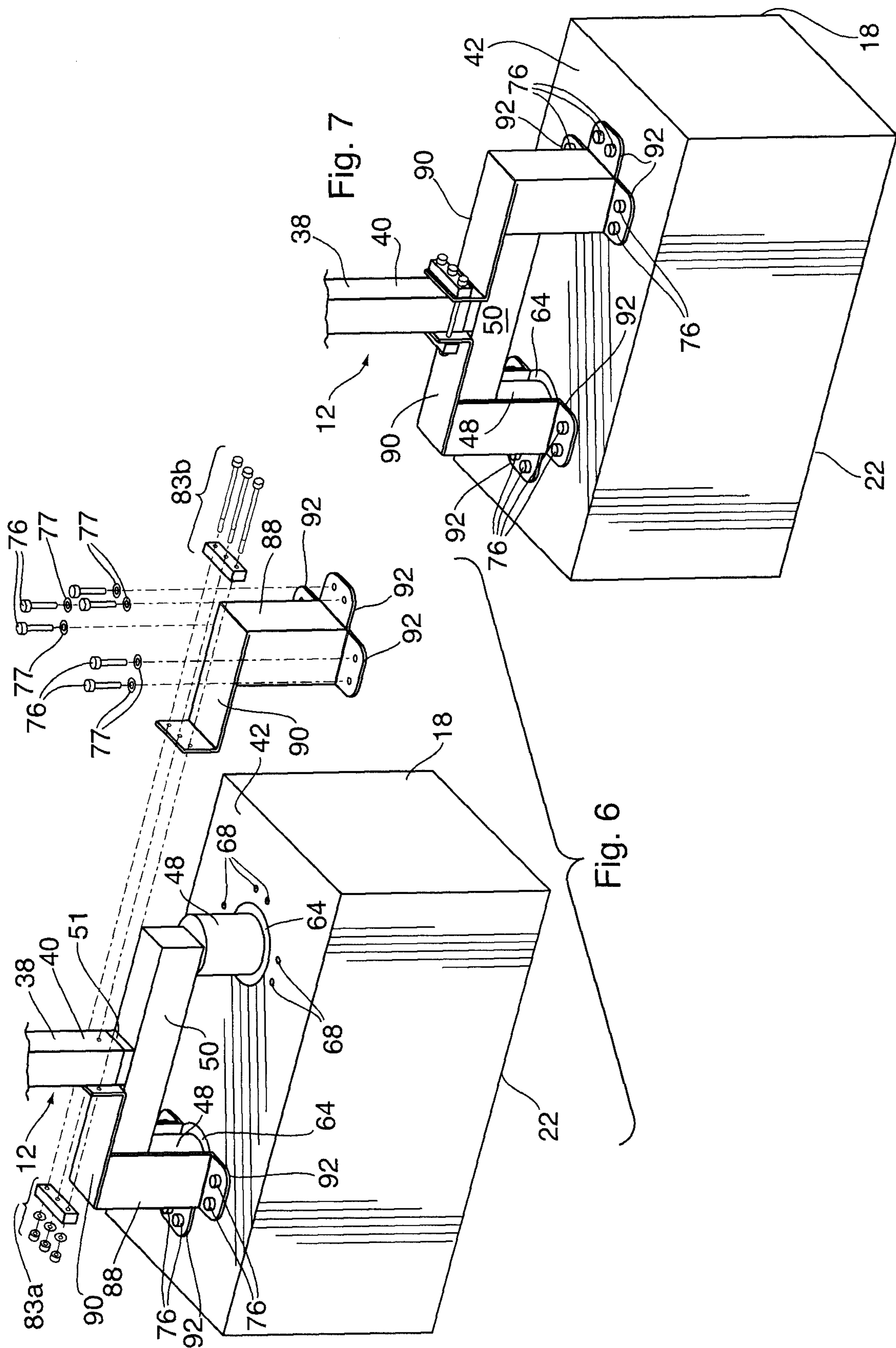
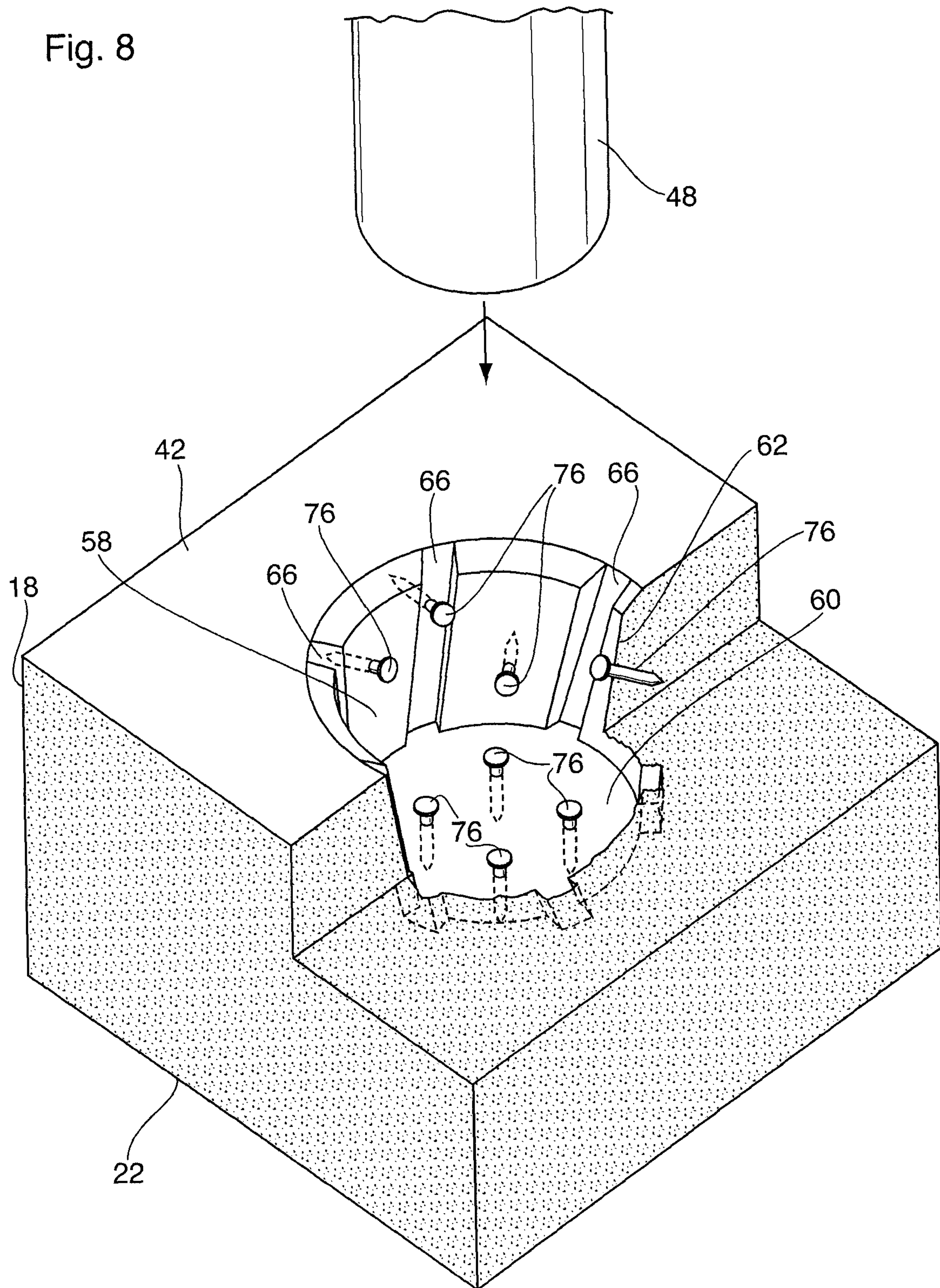
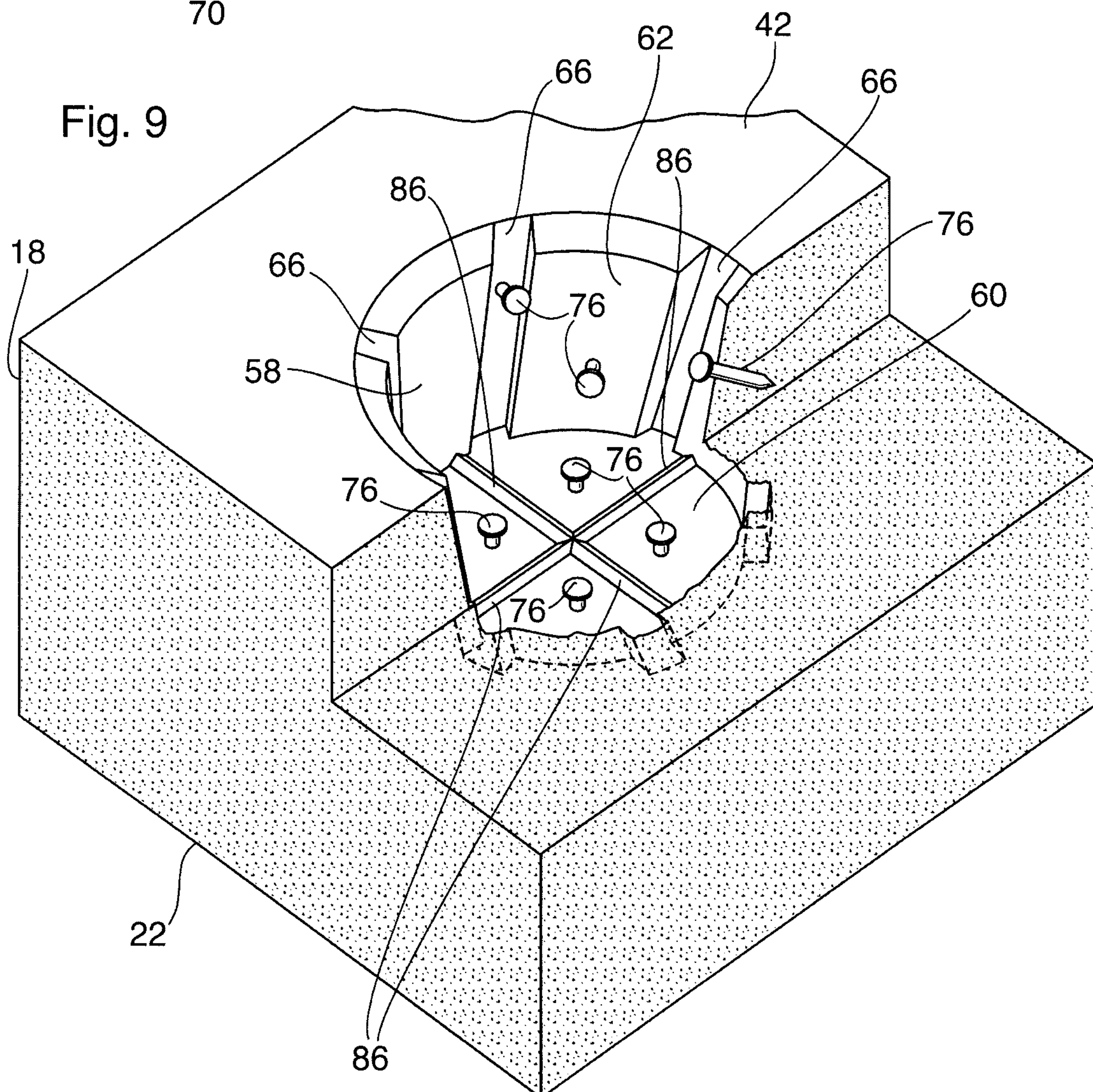
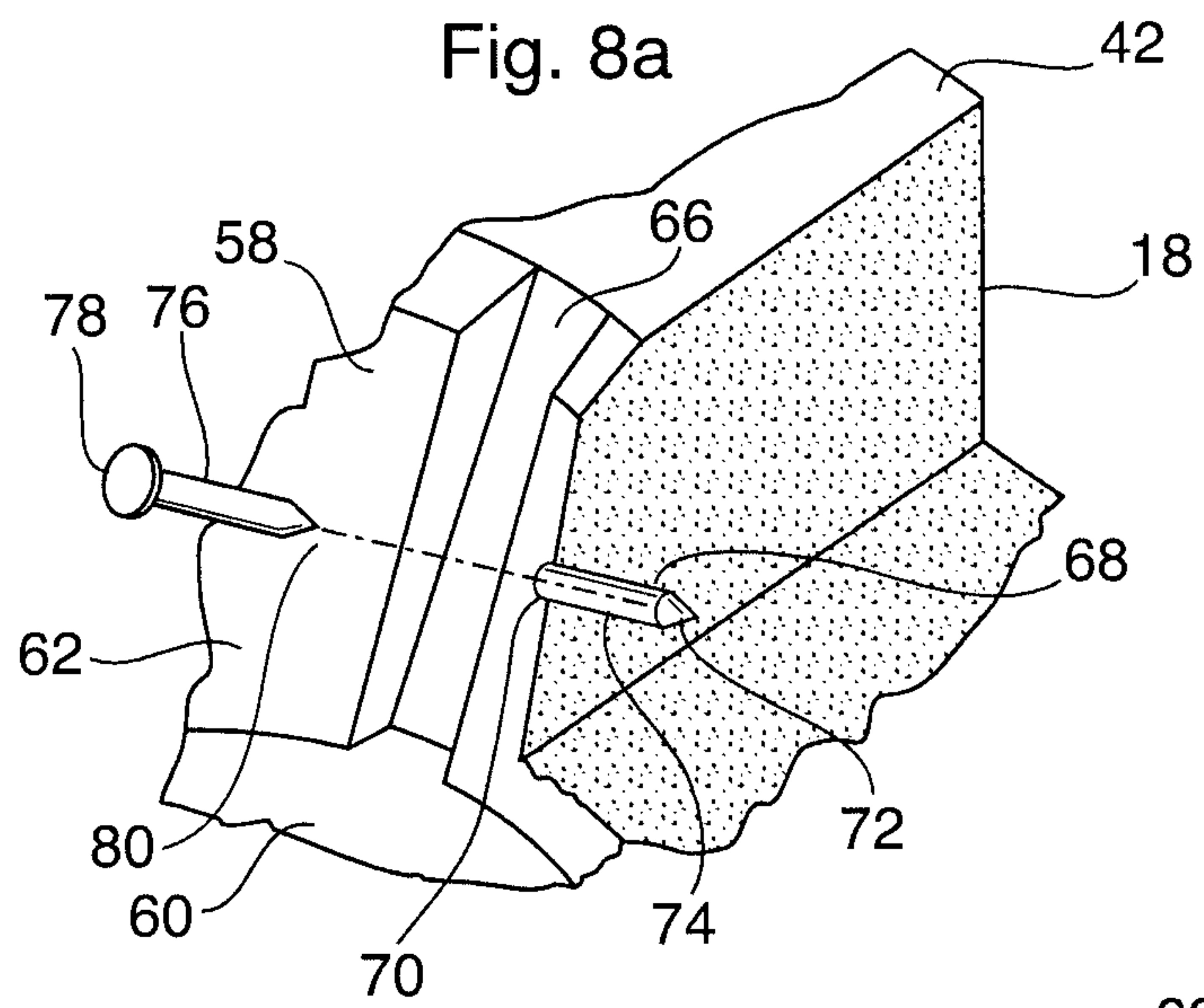


Fig. 8





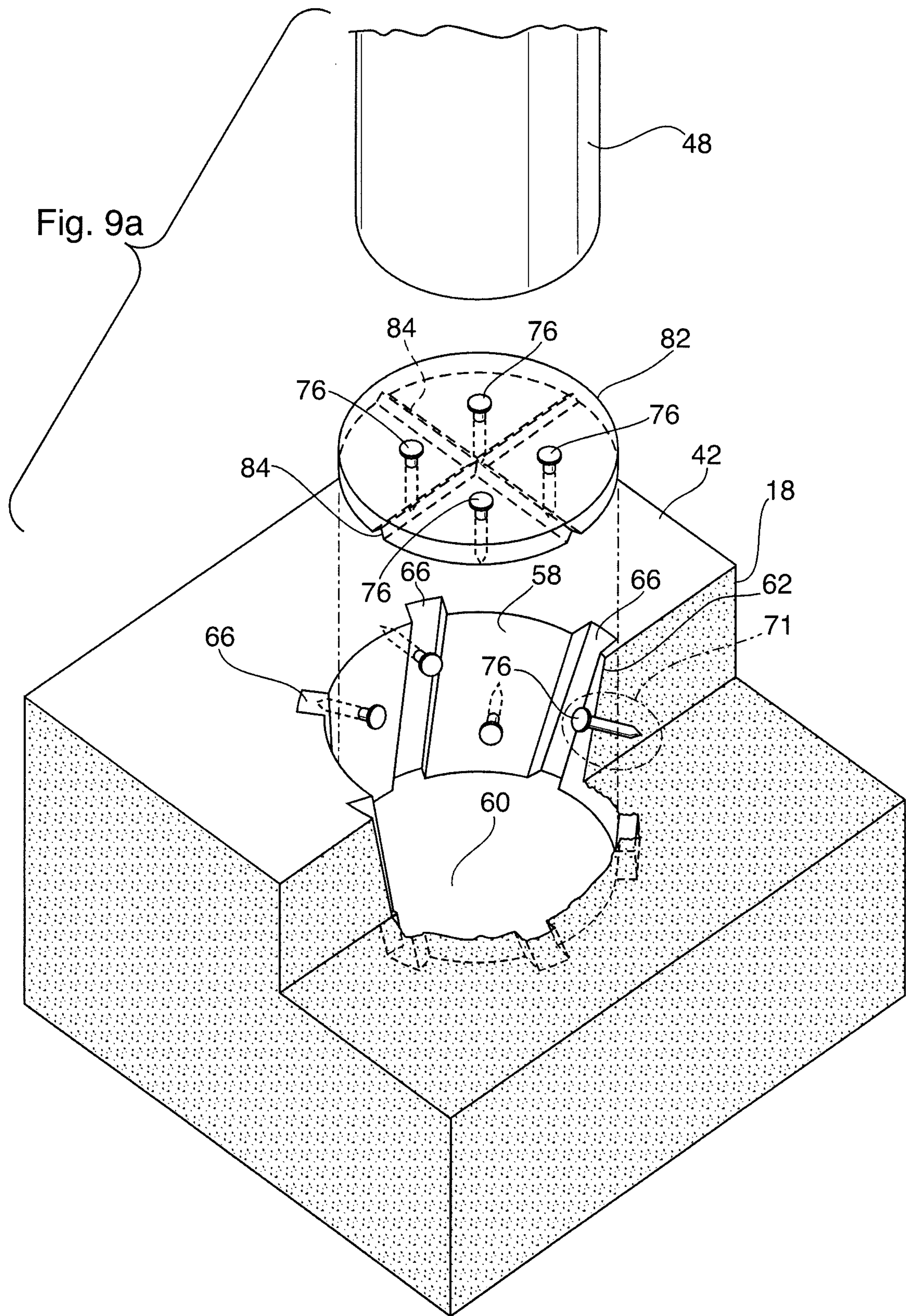


Fig. 10

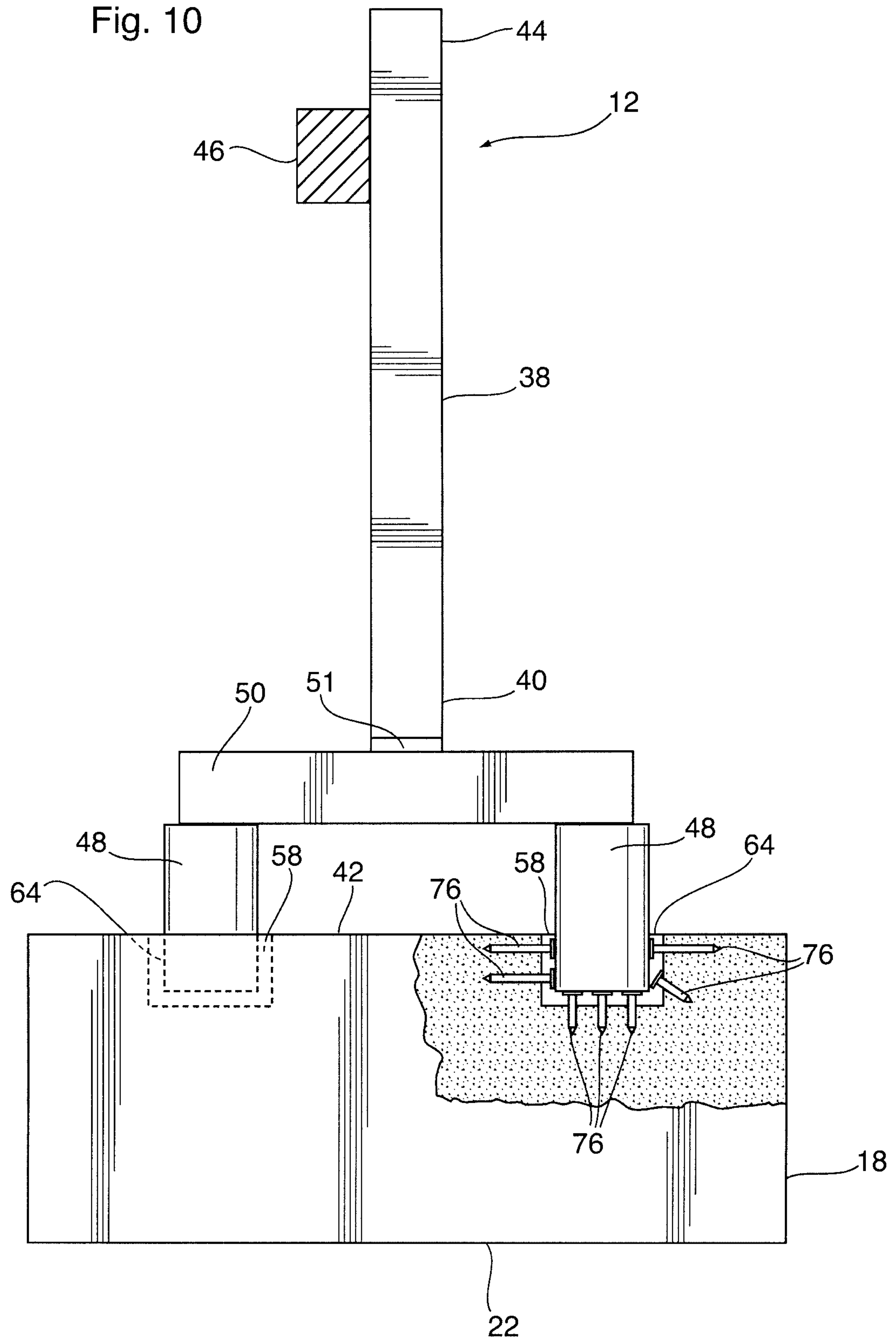


Fig. 11

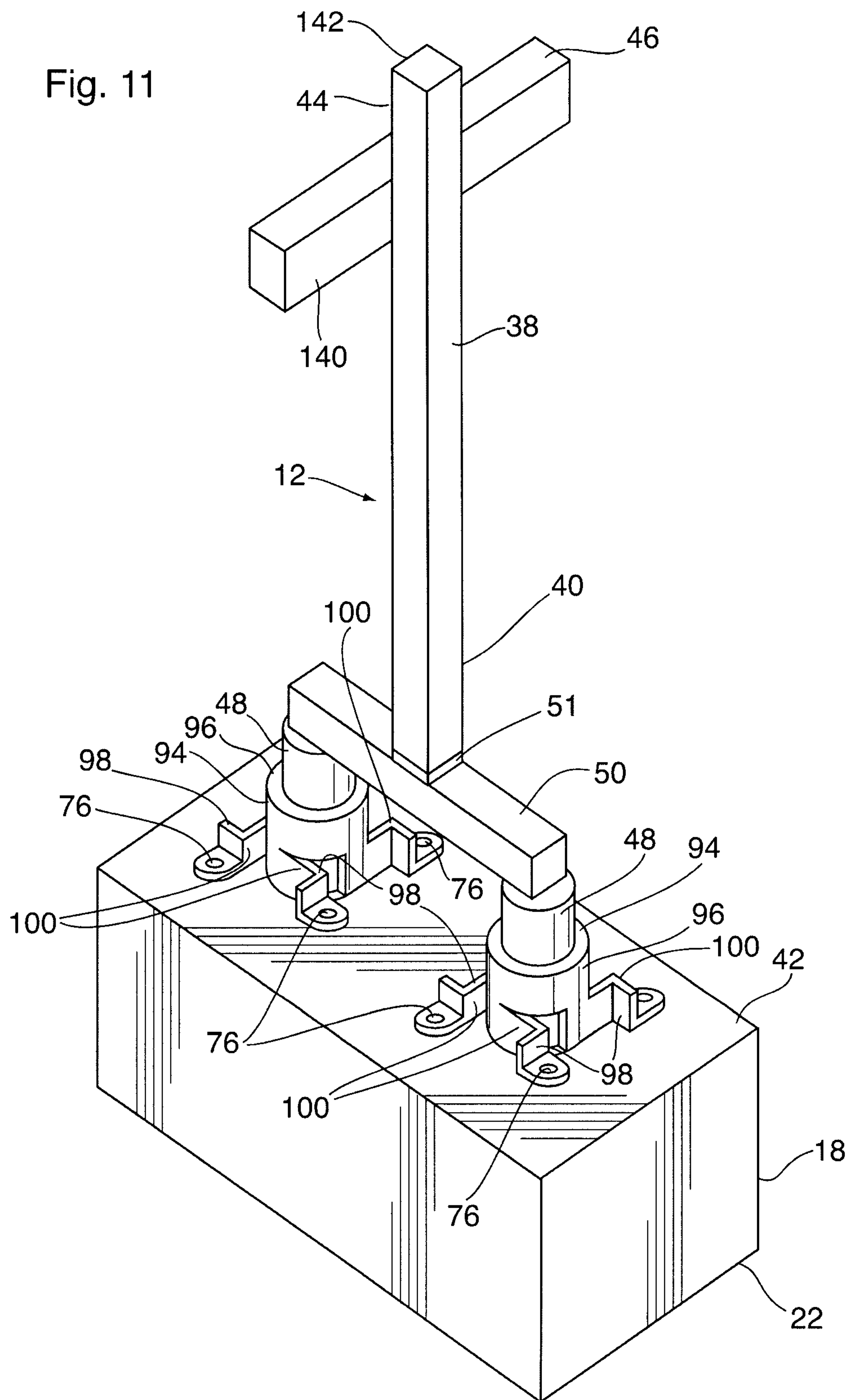


Fig. 12

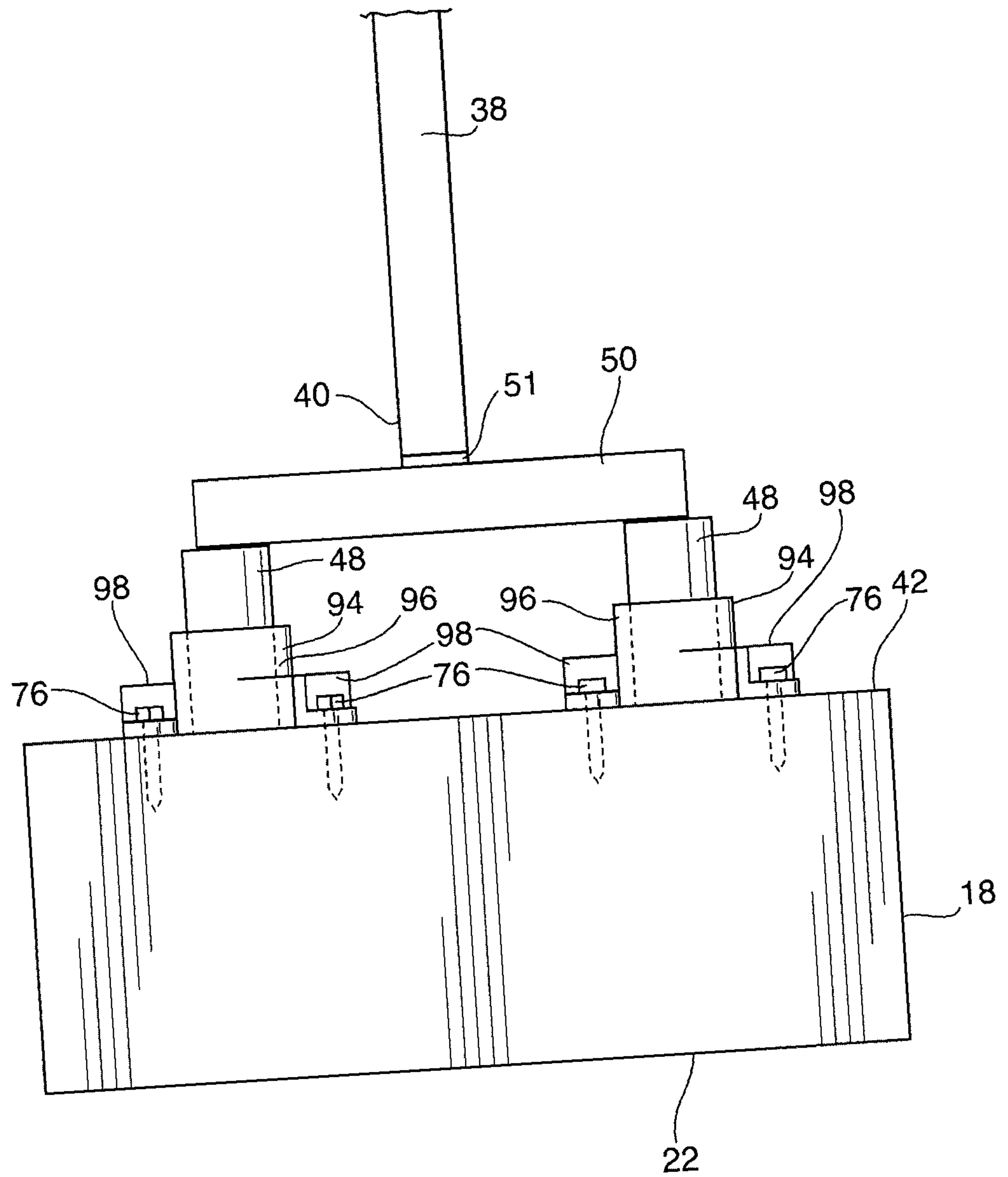


Fig. 13

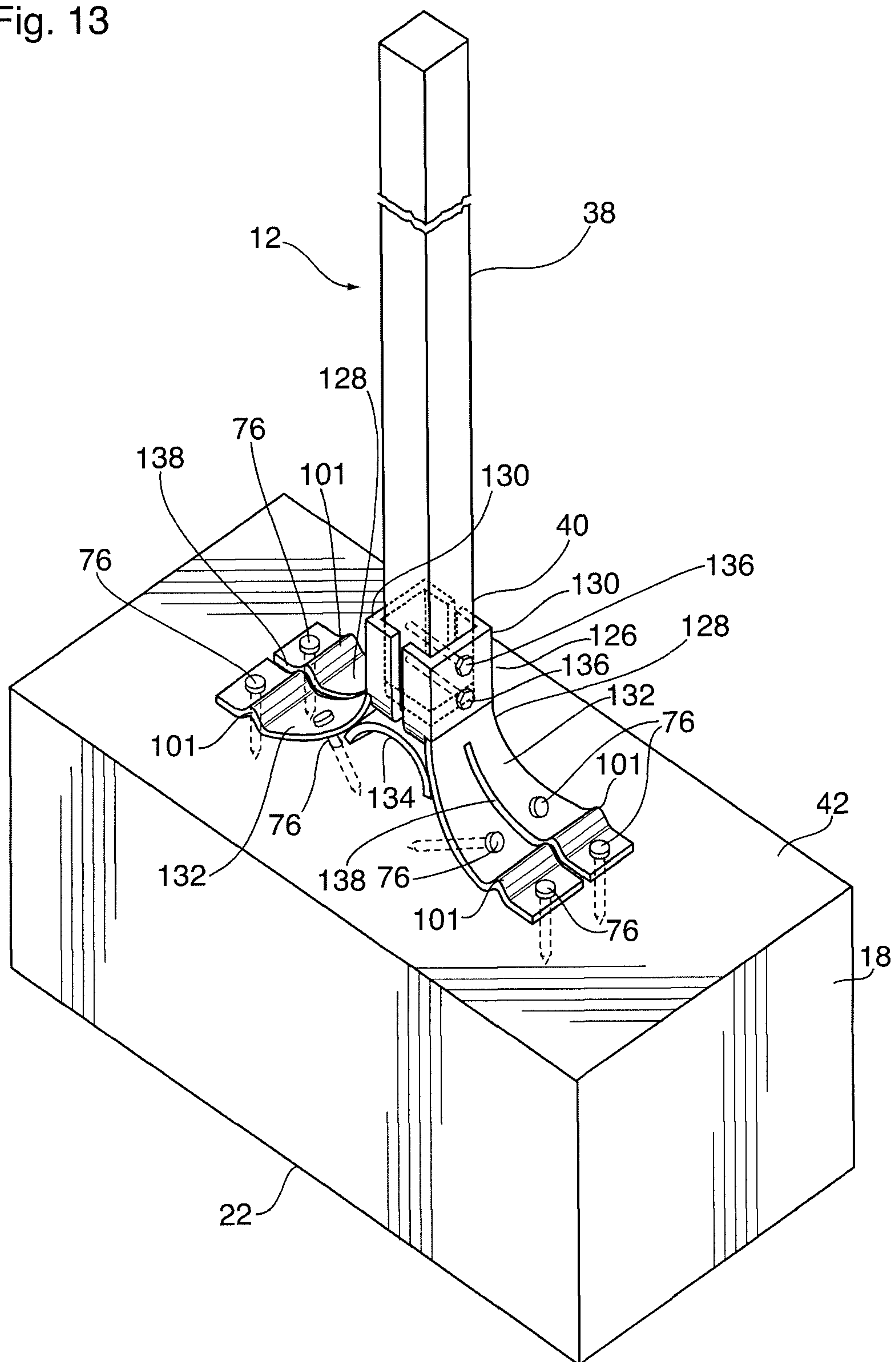


Fig. 14a

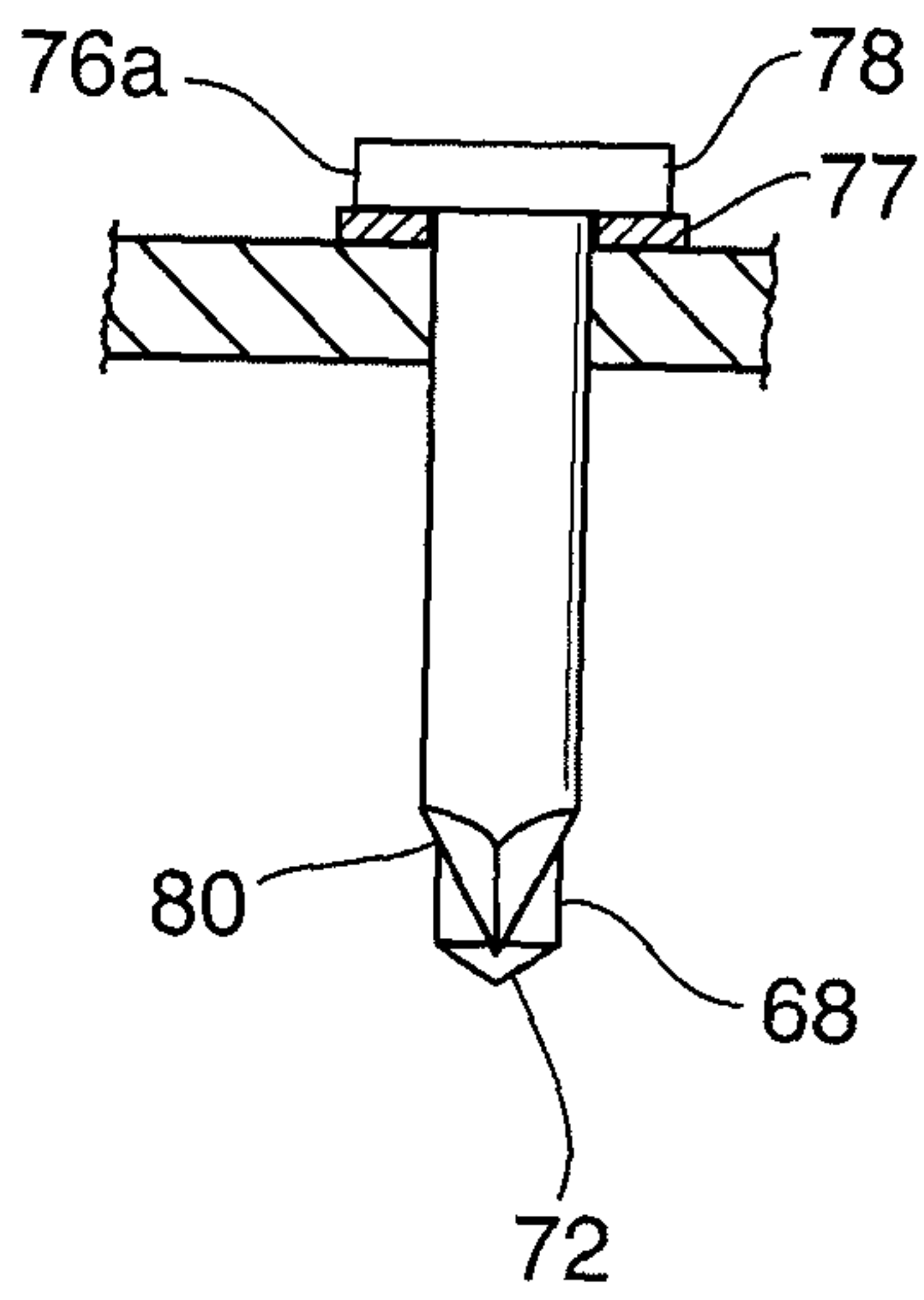


Fig. 14b

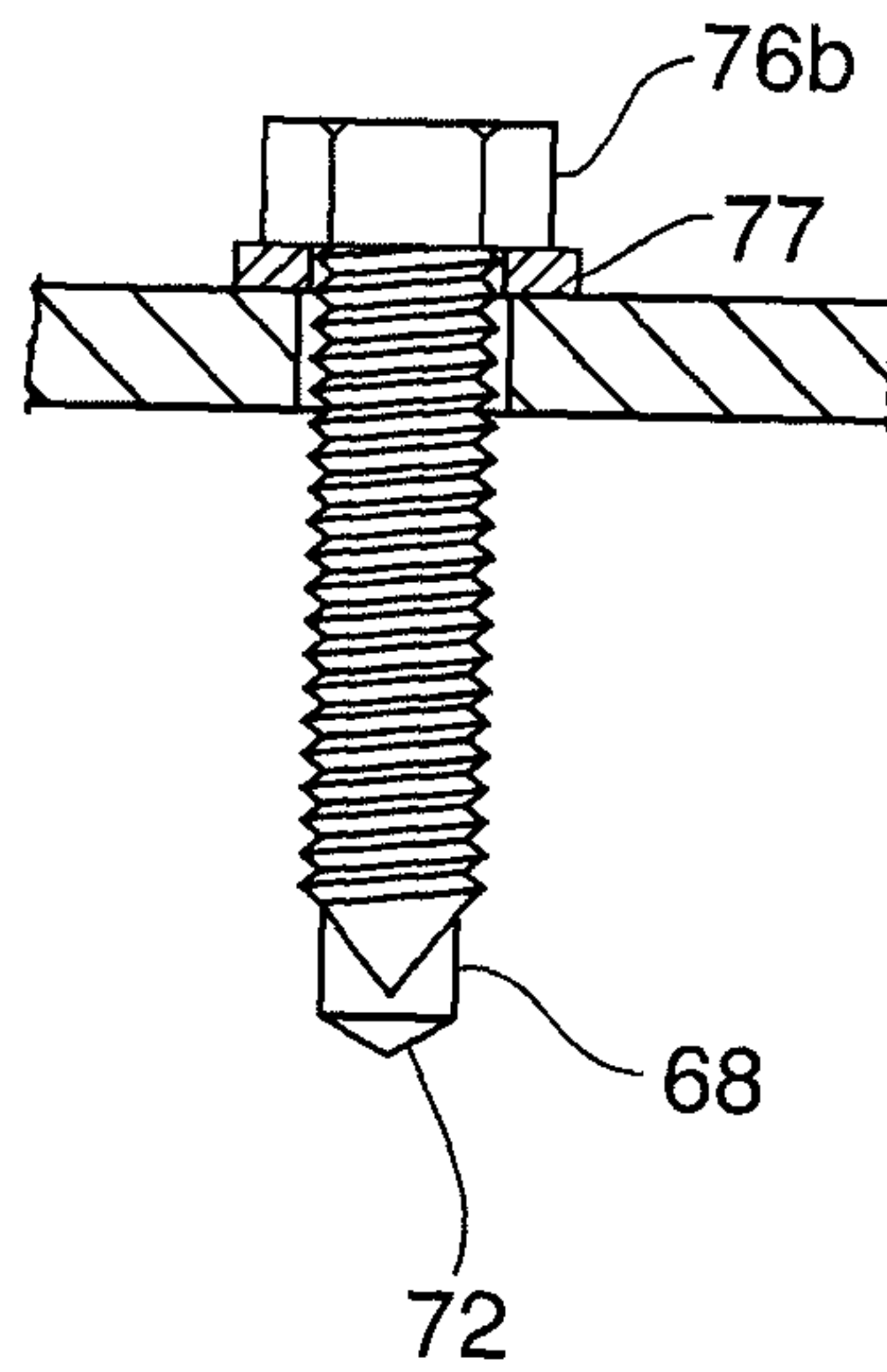


Fig. 14c

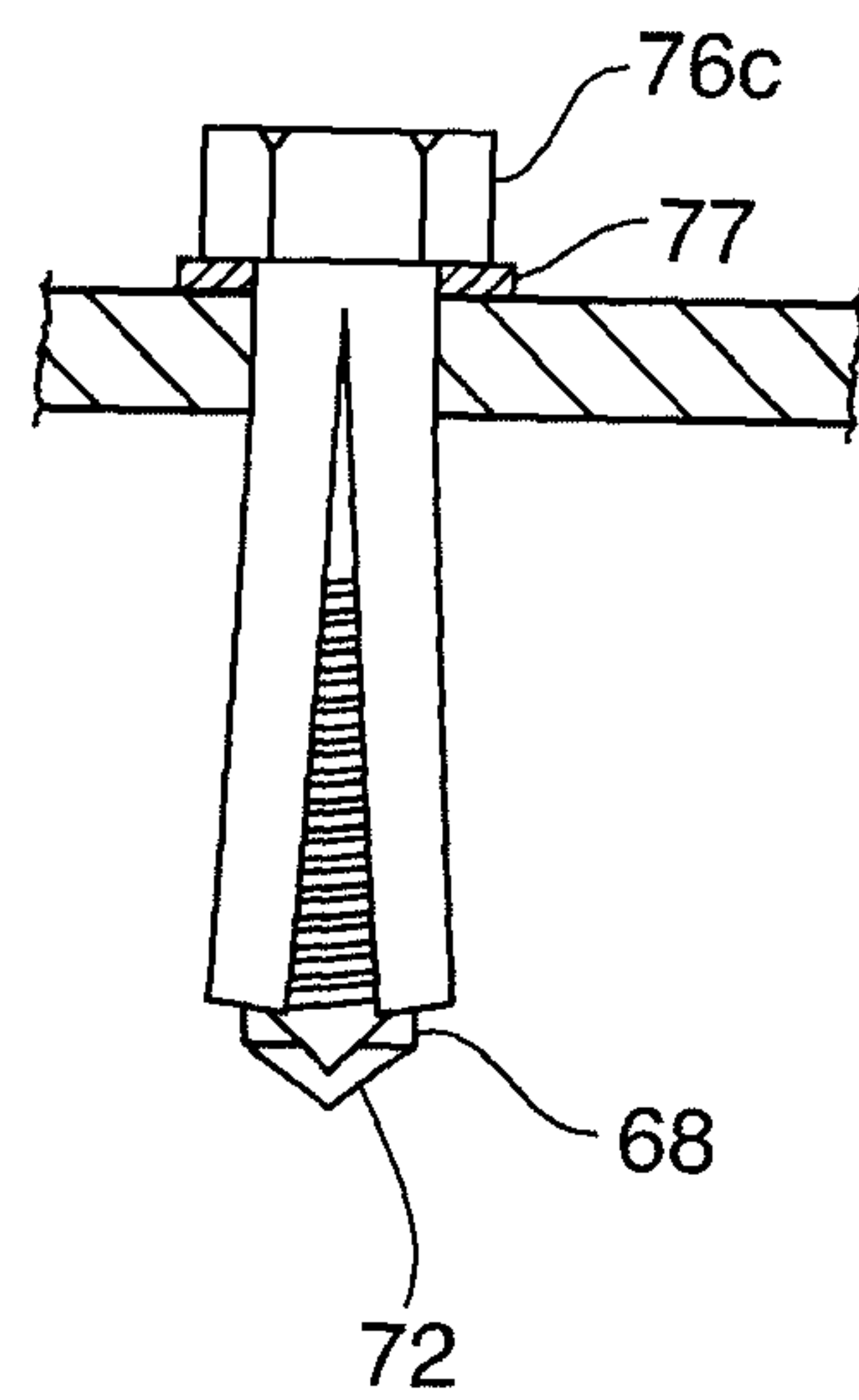


Fig. 14d

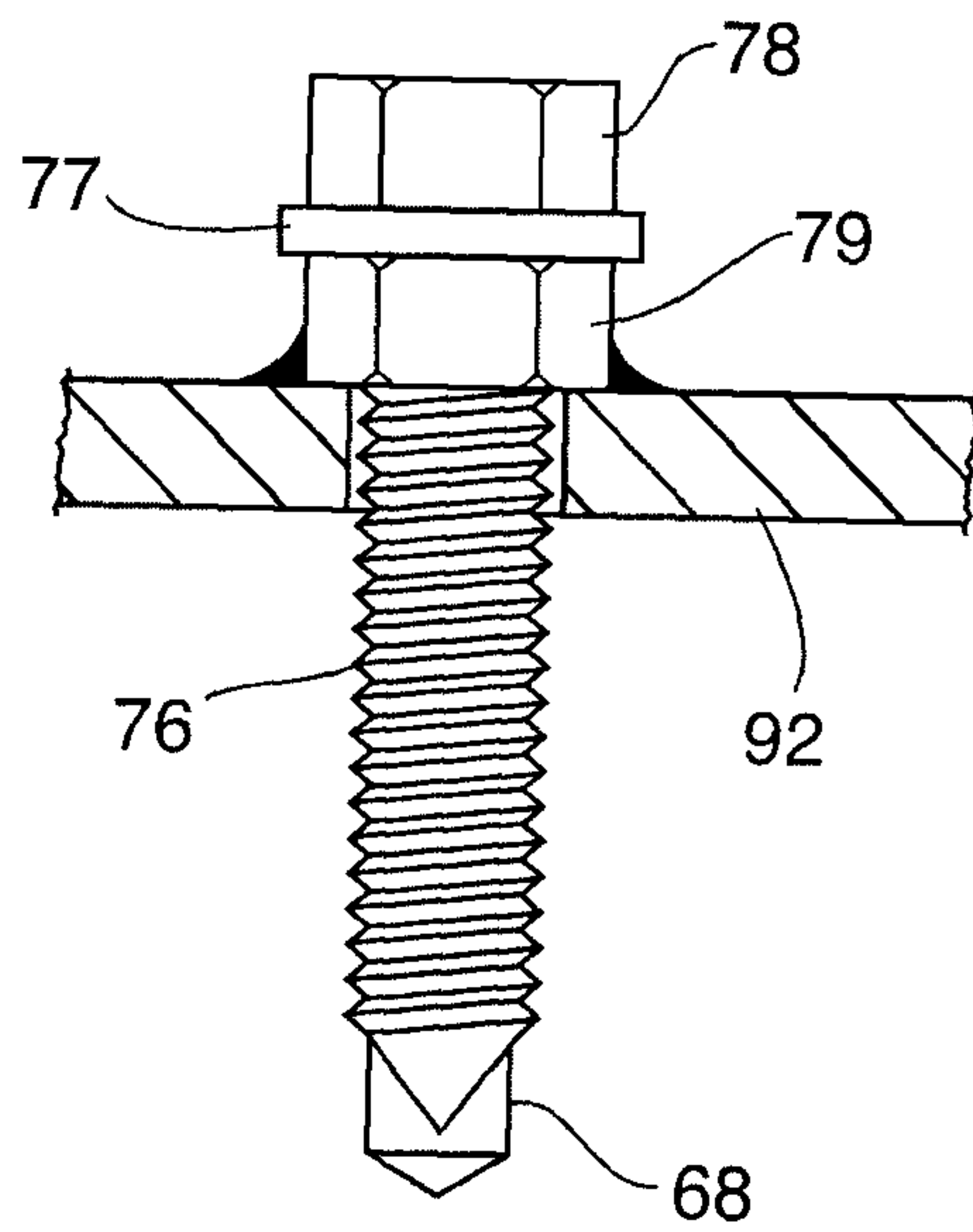
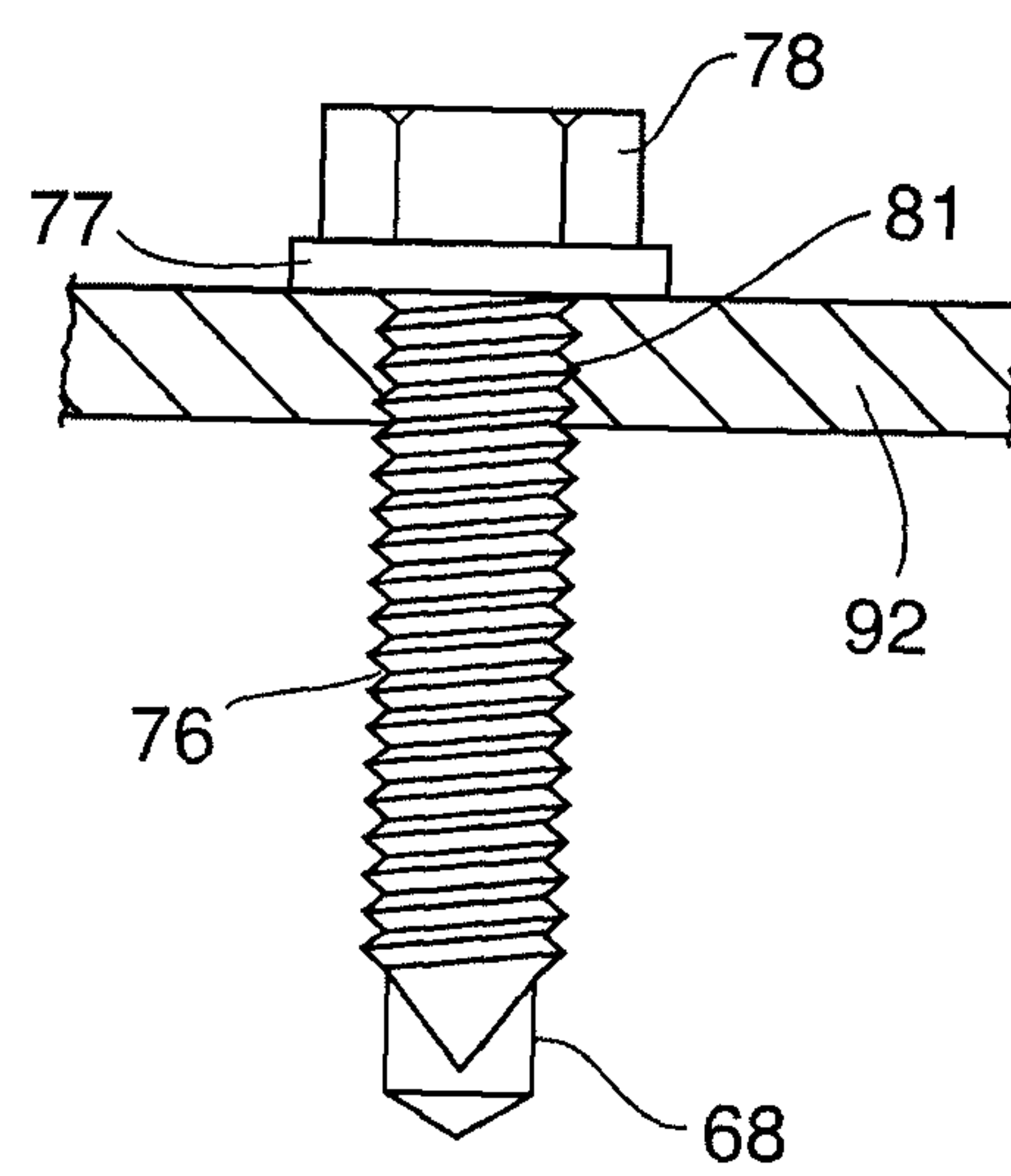
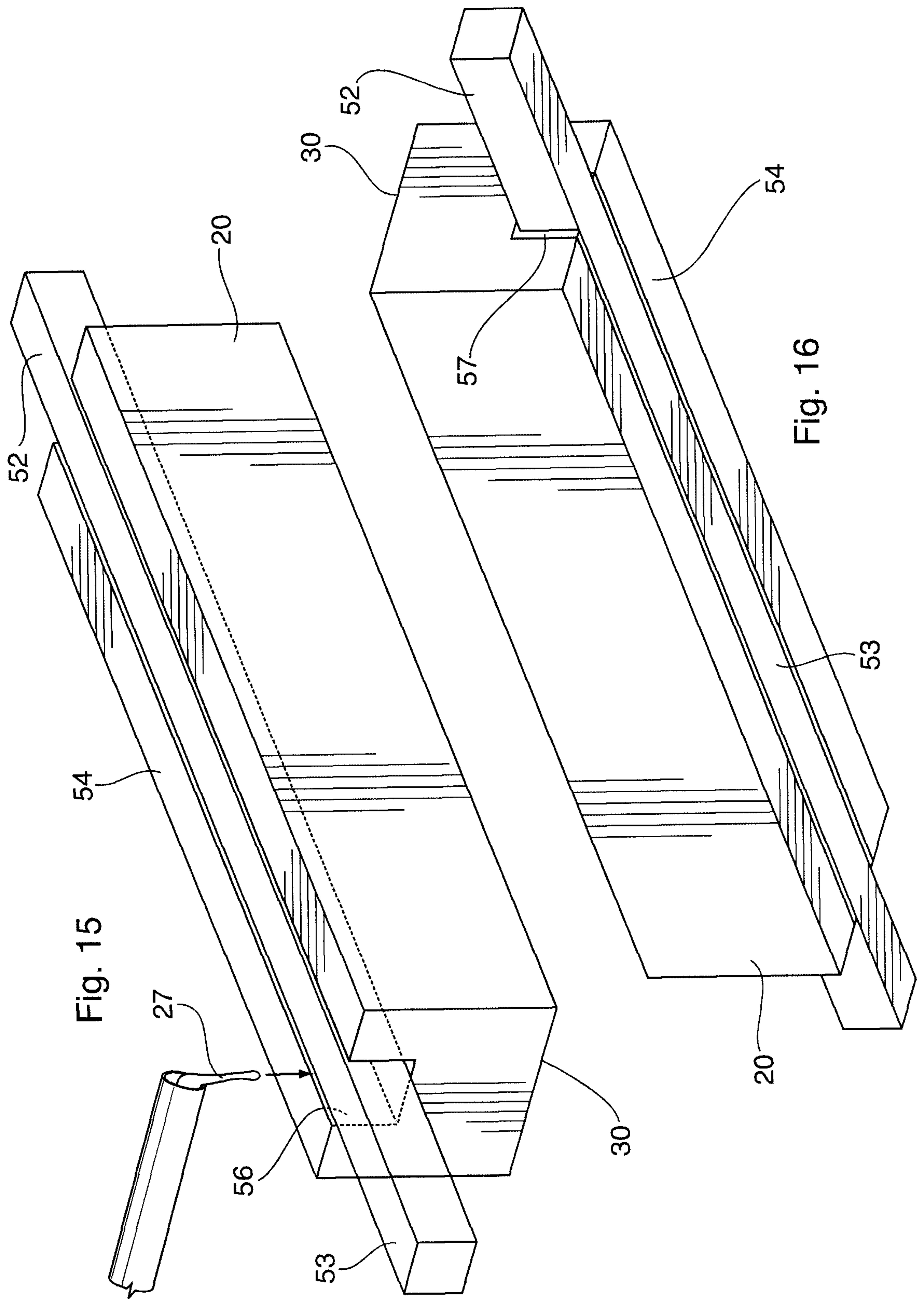


Fig. 14e





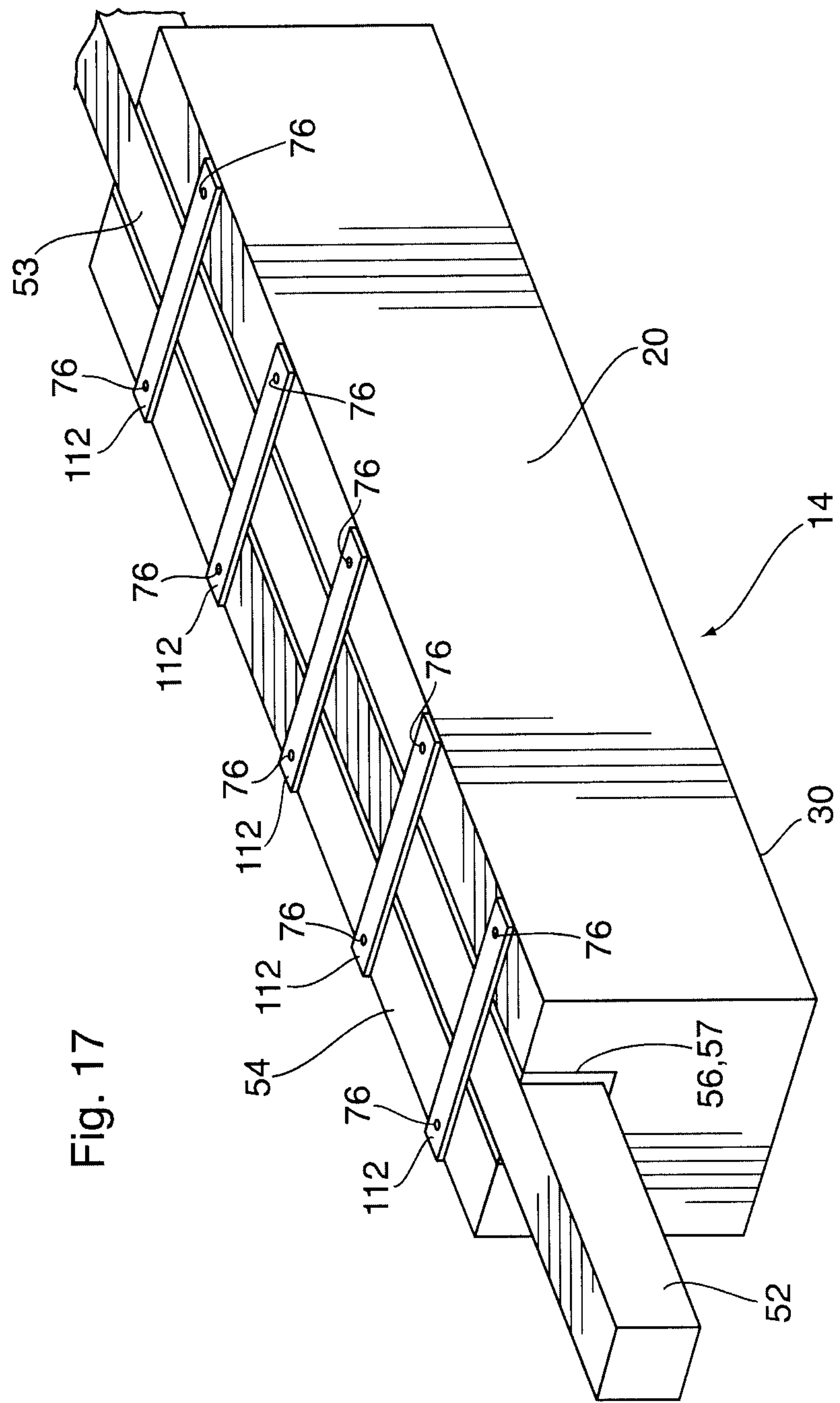
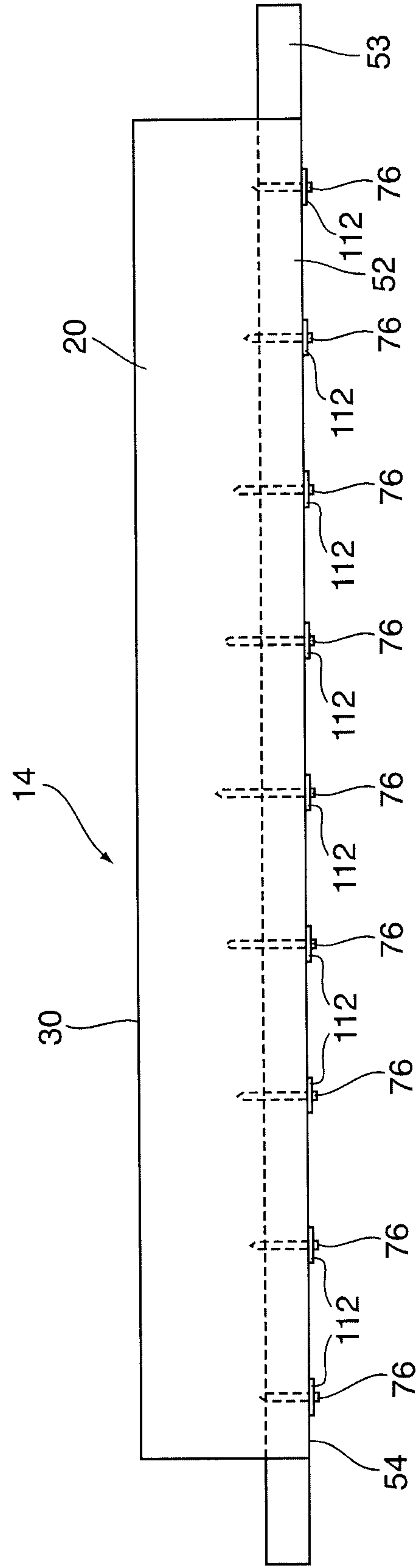


Fig. 18



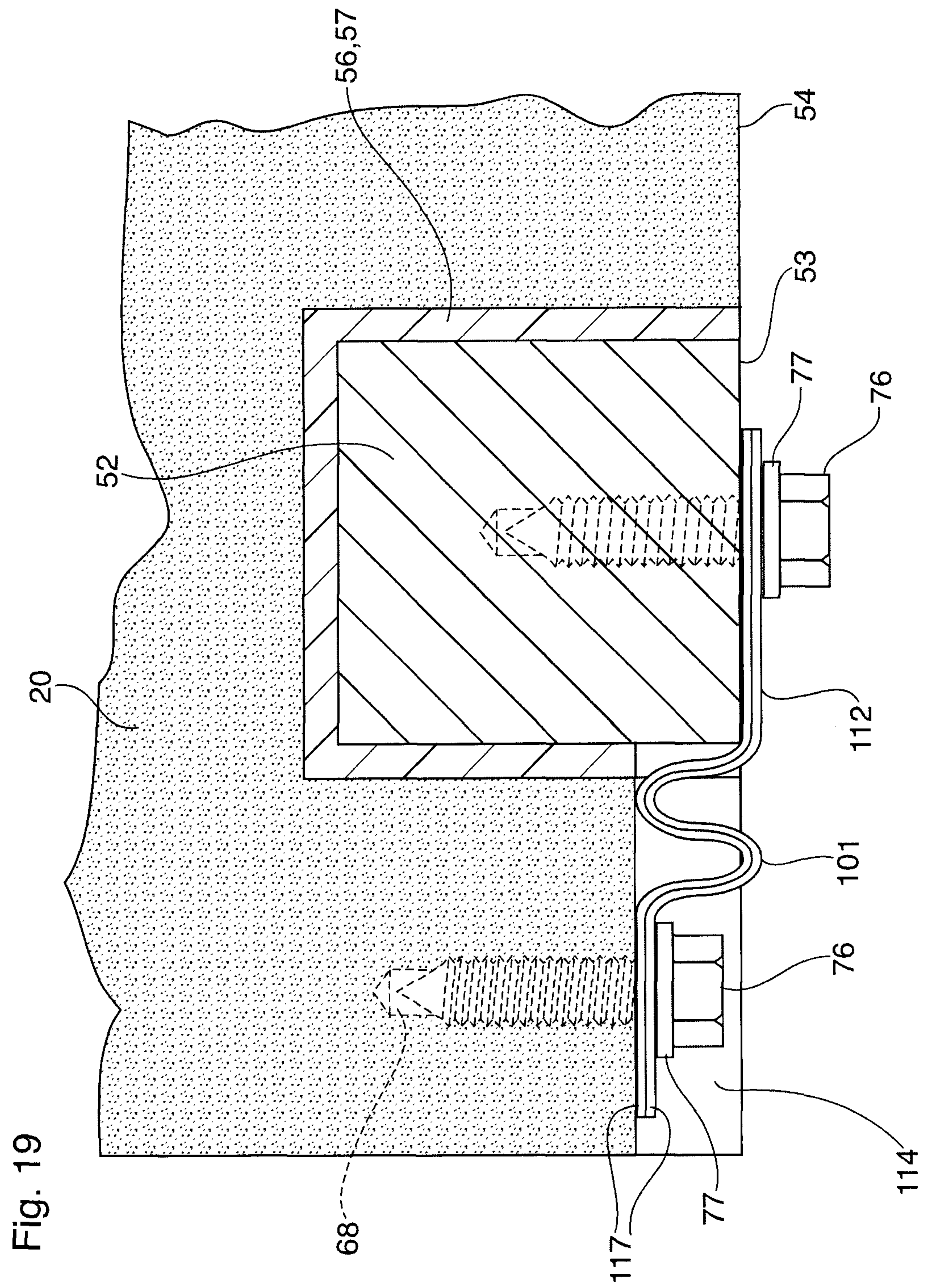
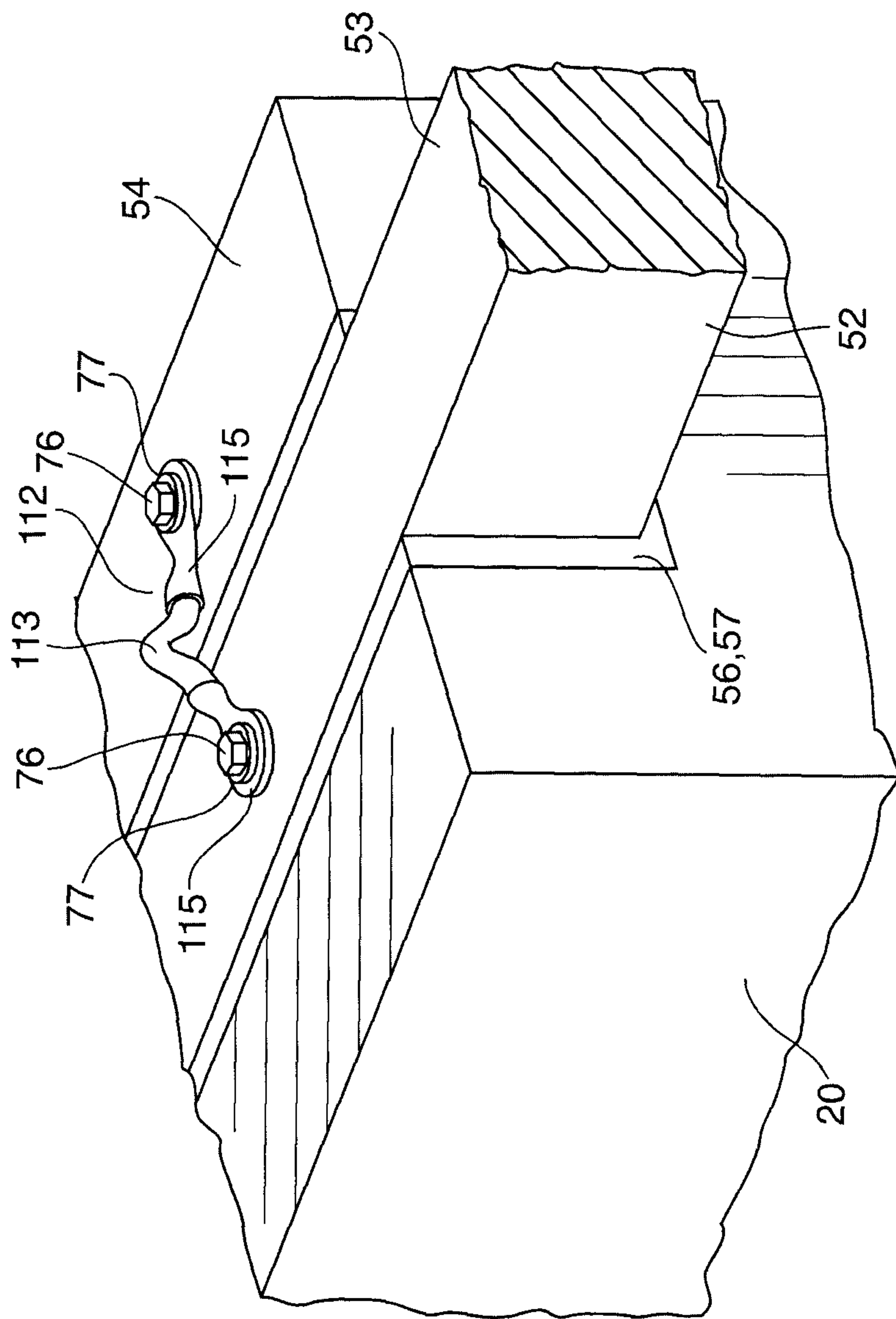


Fig. 20



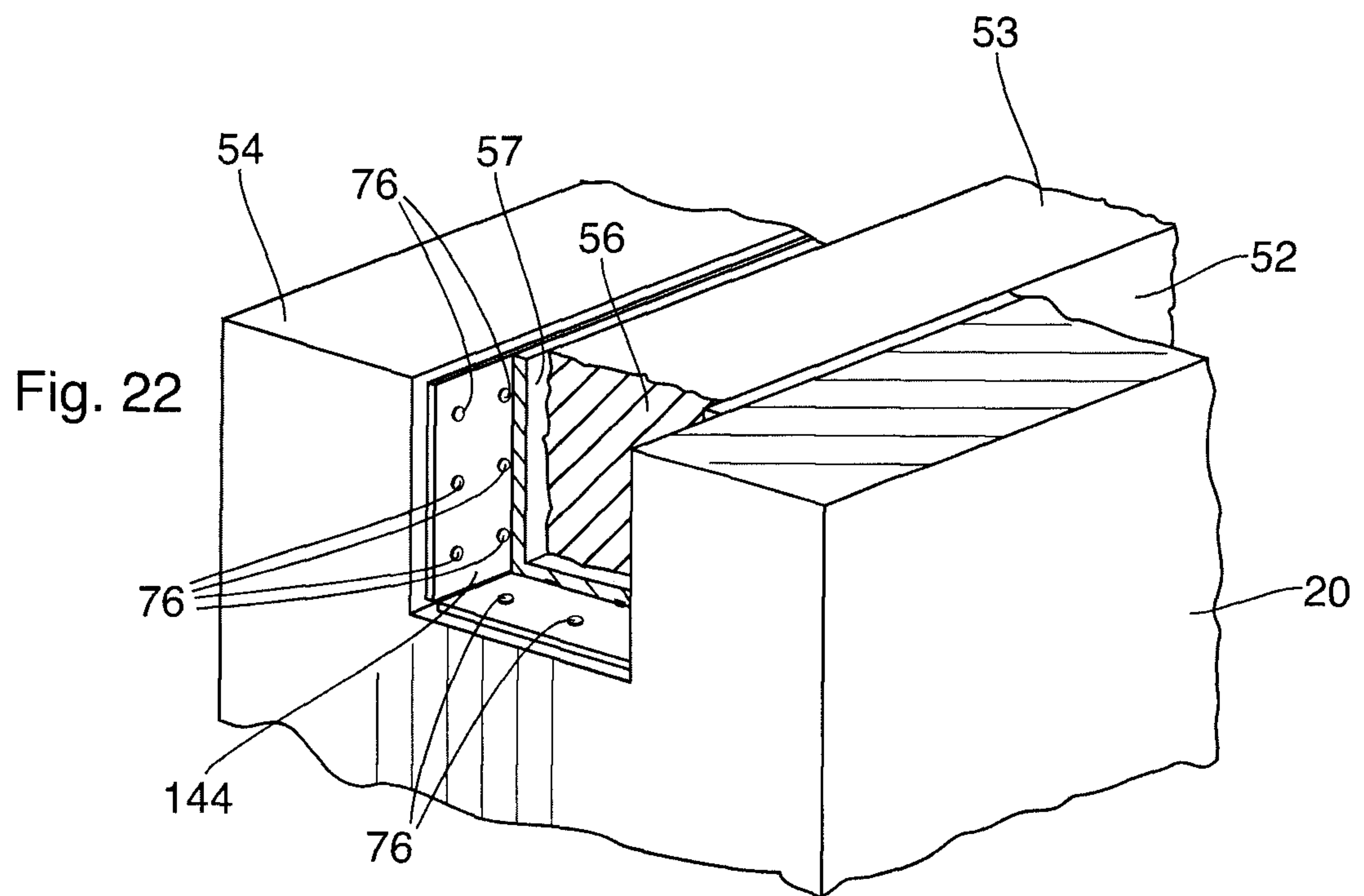
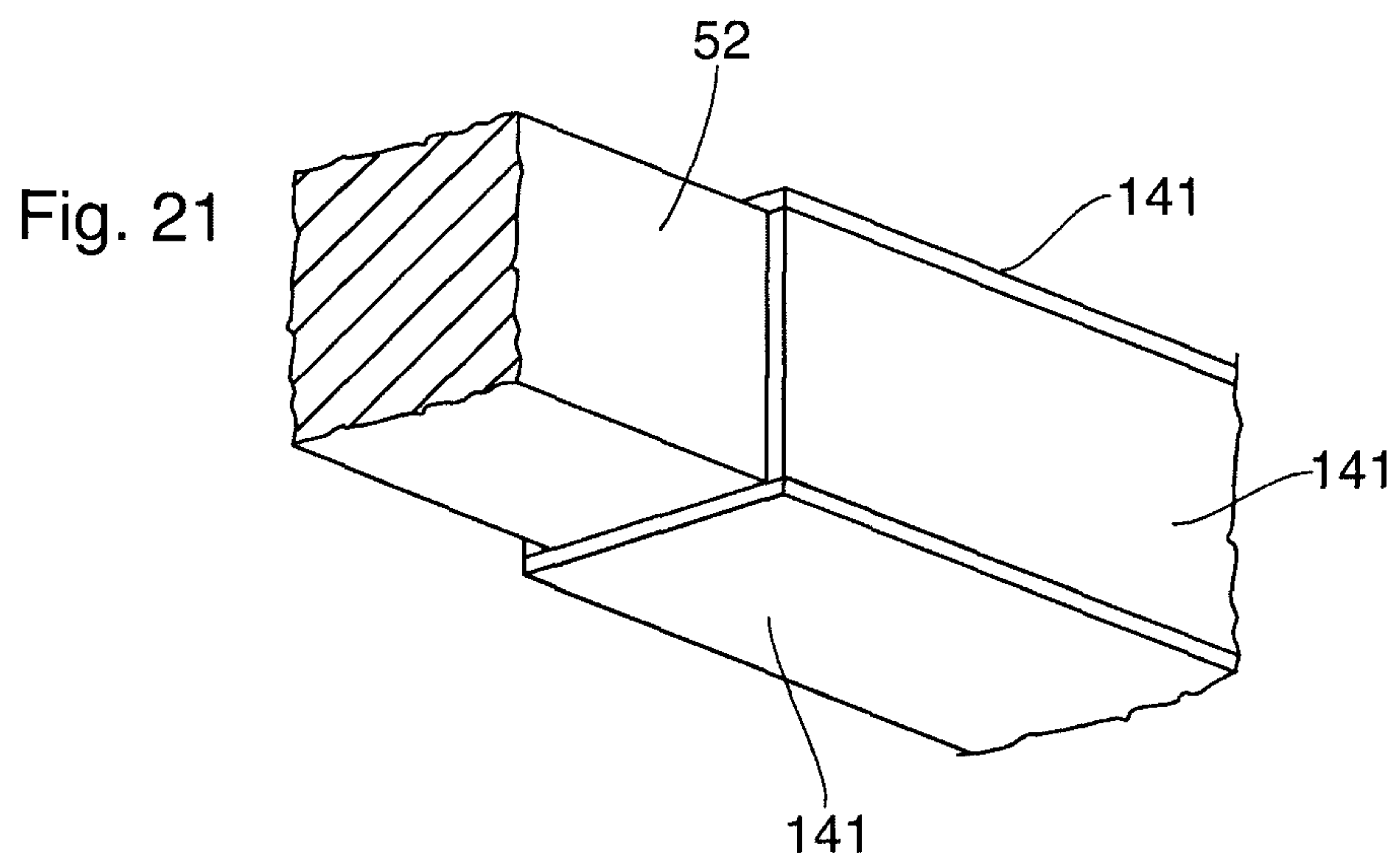


Fig. 23

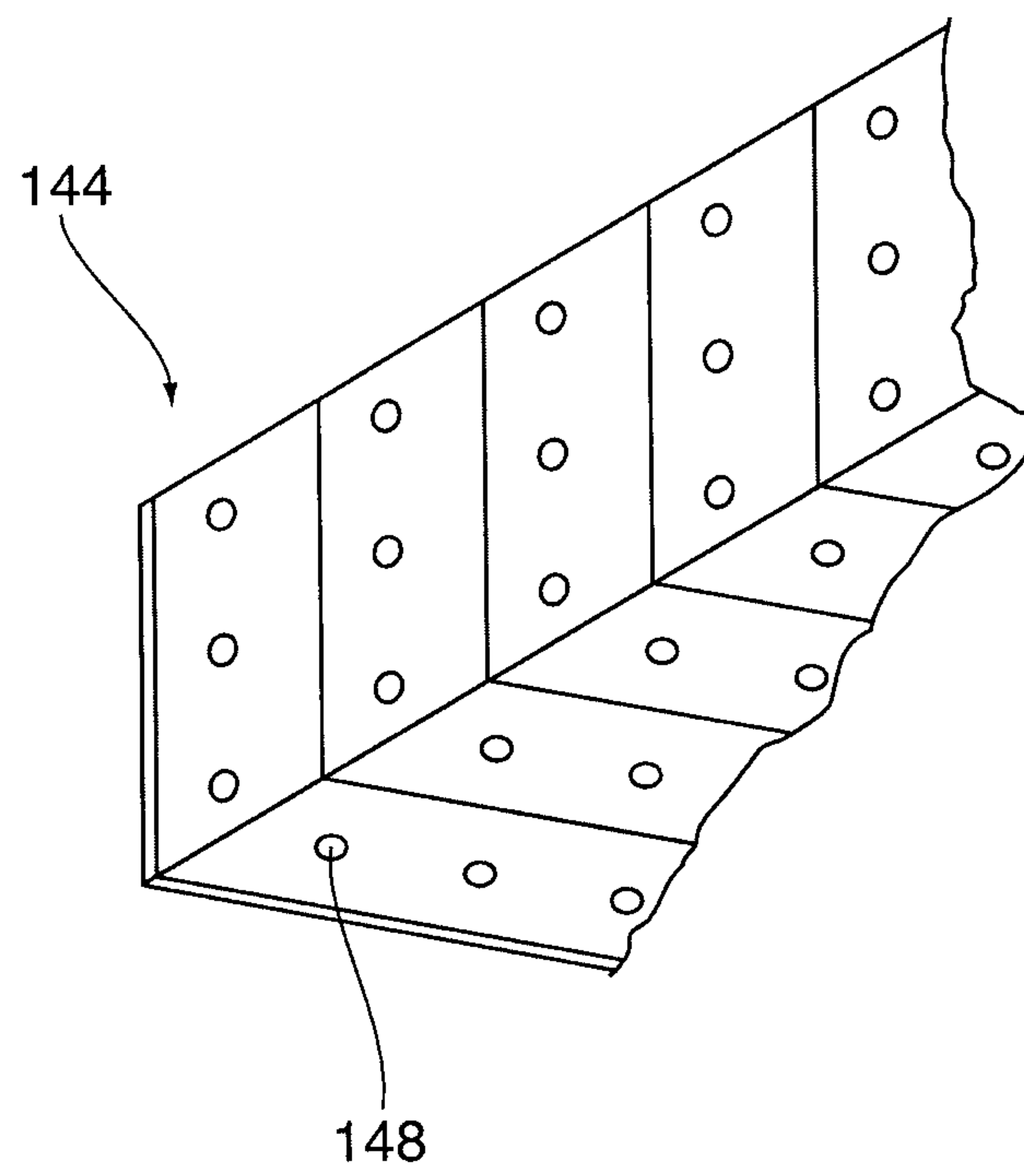
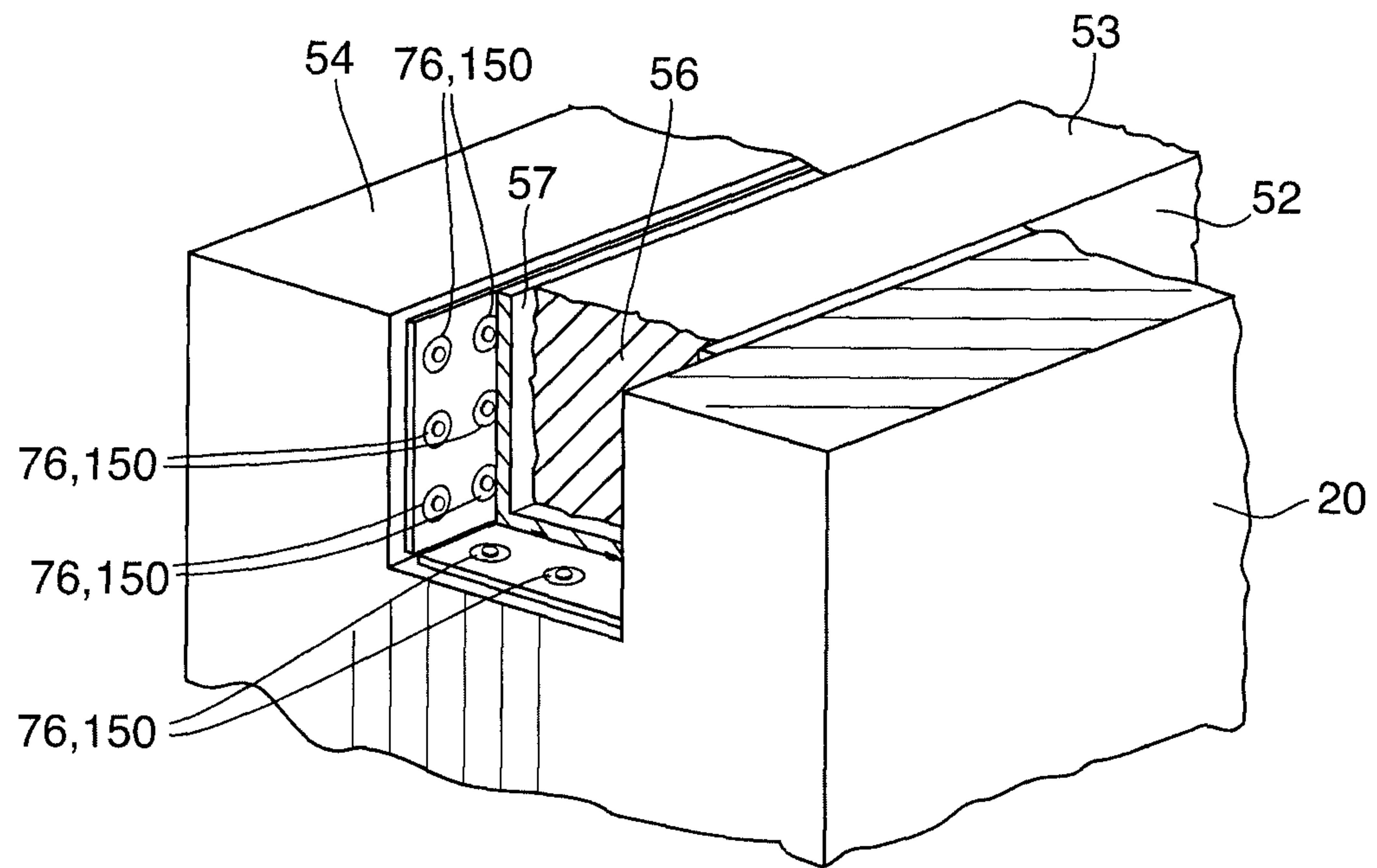


Fig. 24



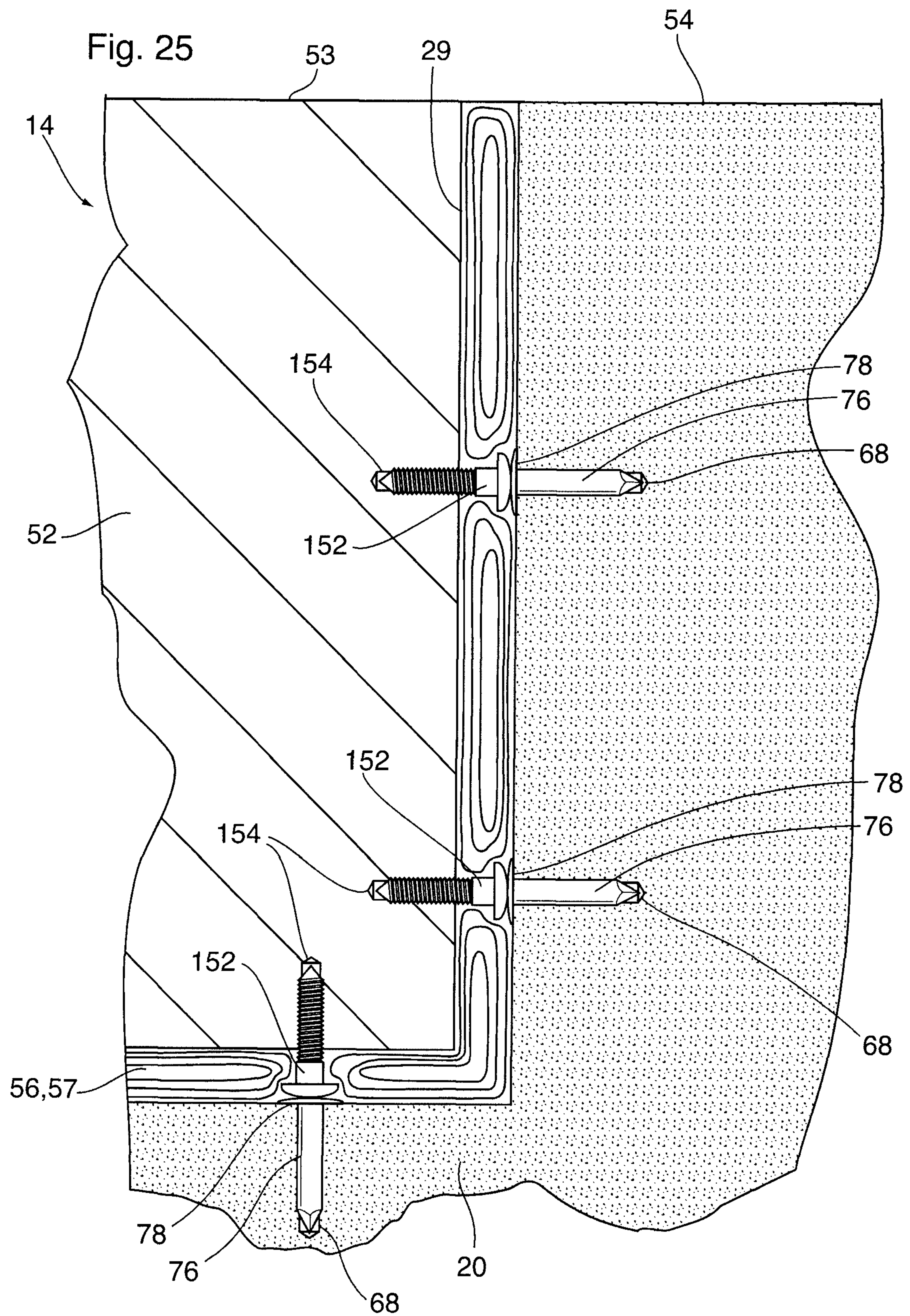


Fig. 26

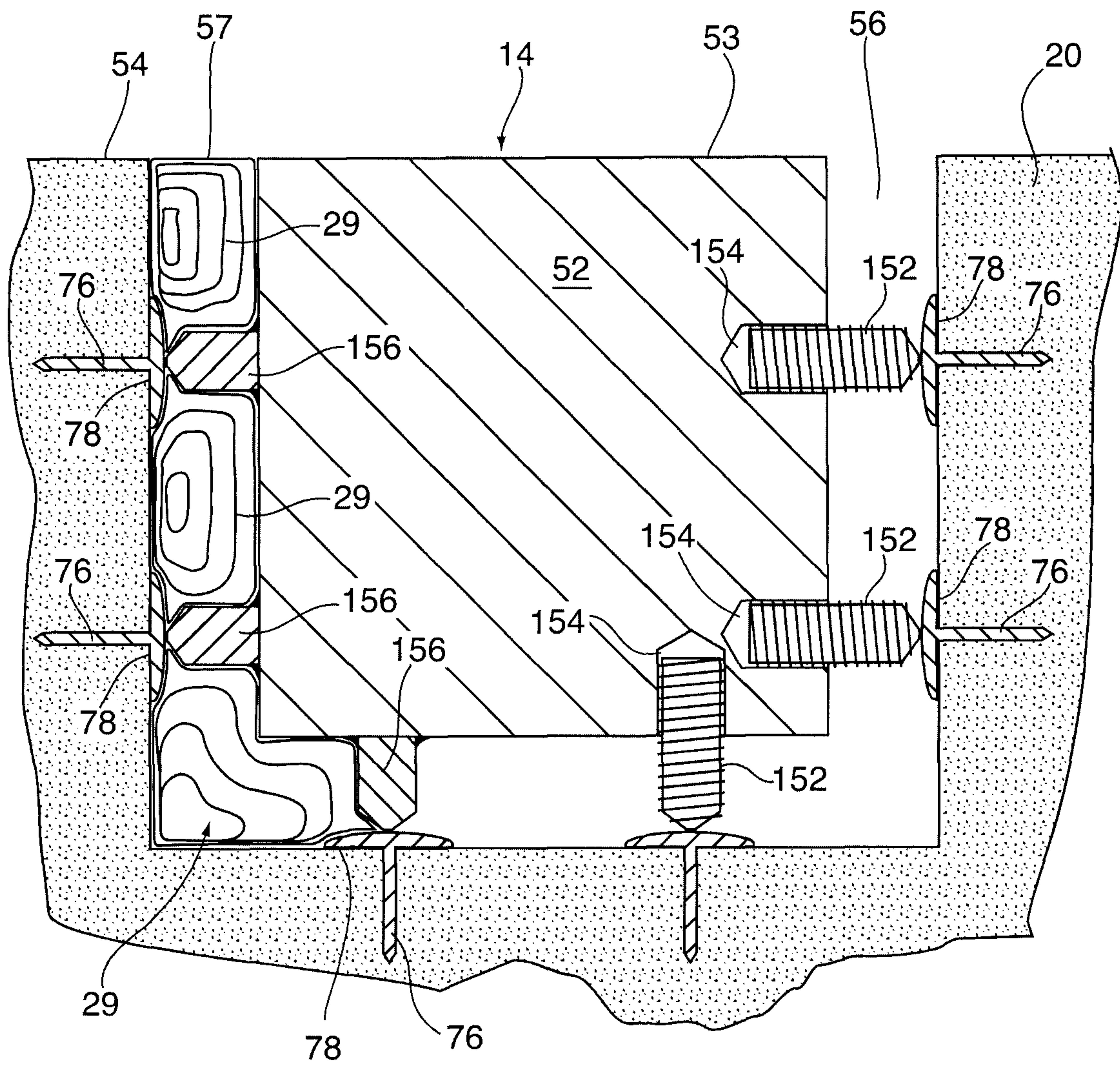


Fig. 27

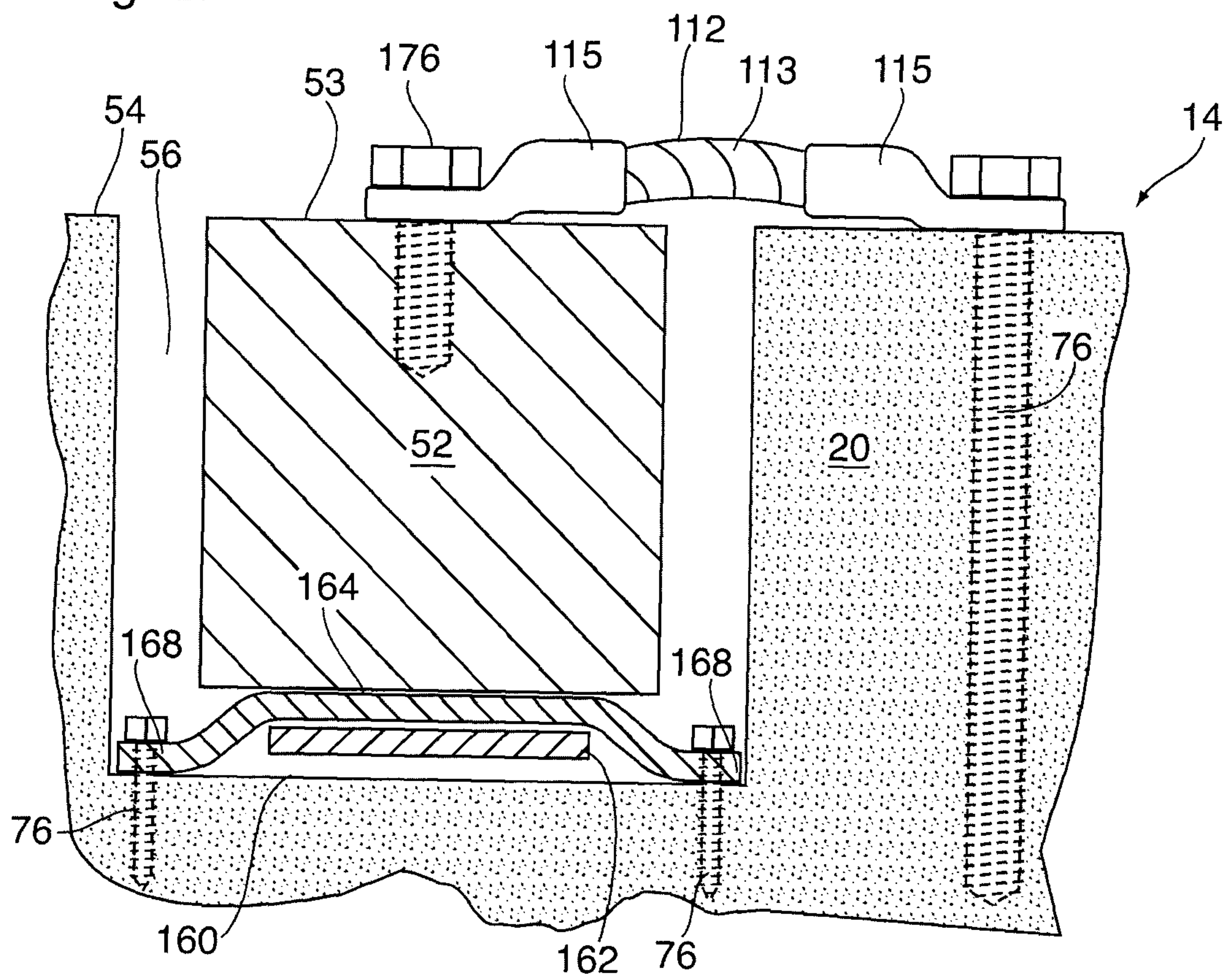


Fig. 28

