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(54) LOW RESISTANCE ELECTRODE ASSEMBLIES FOR PRODUCTION OF METALS

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(57) 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.

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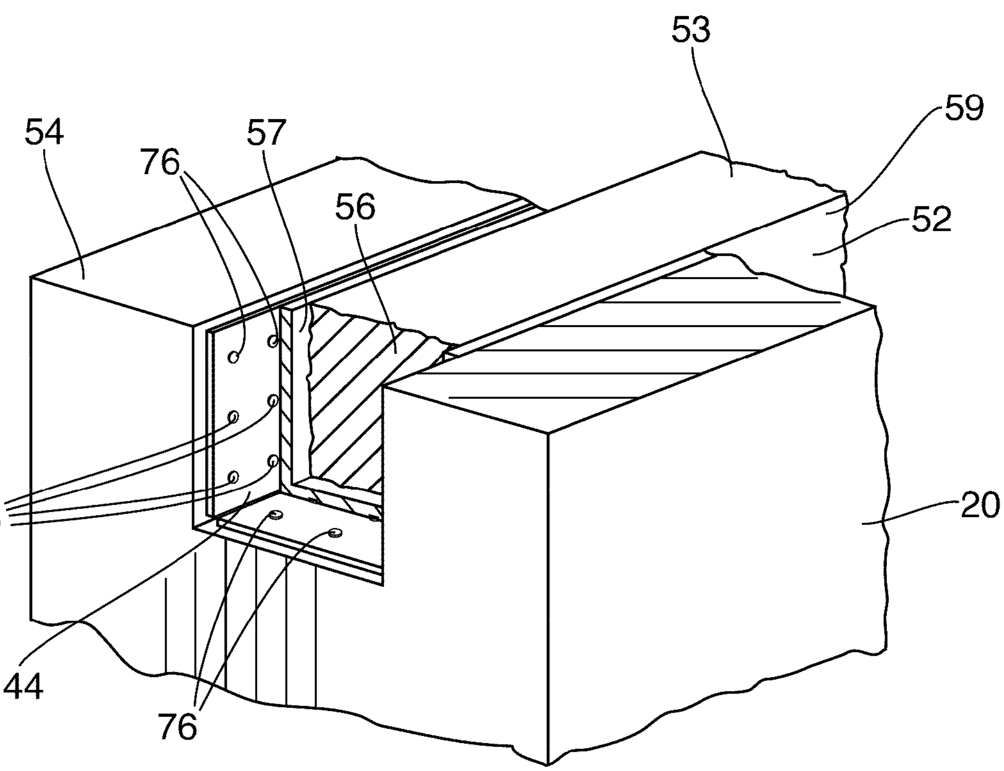

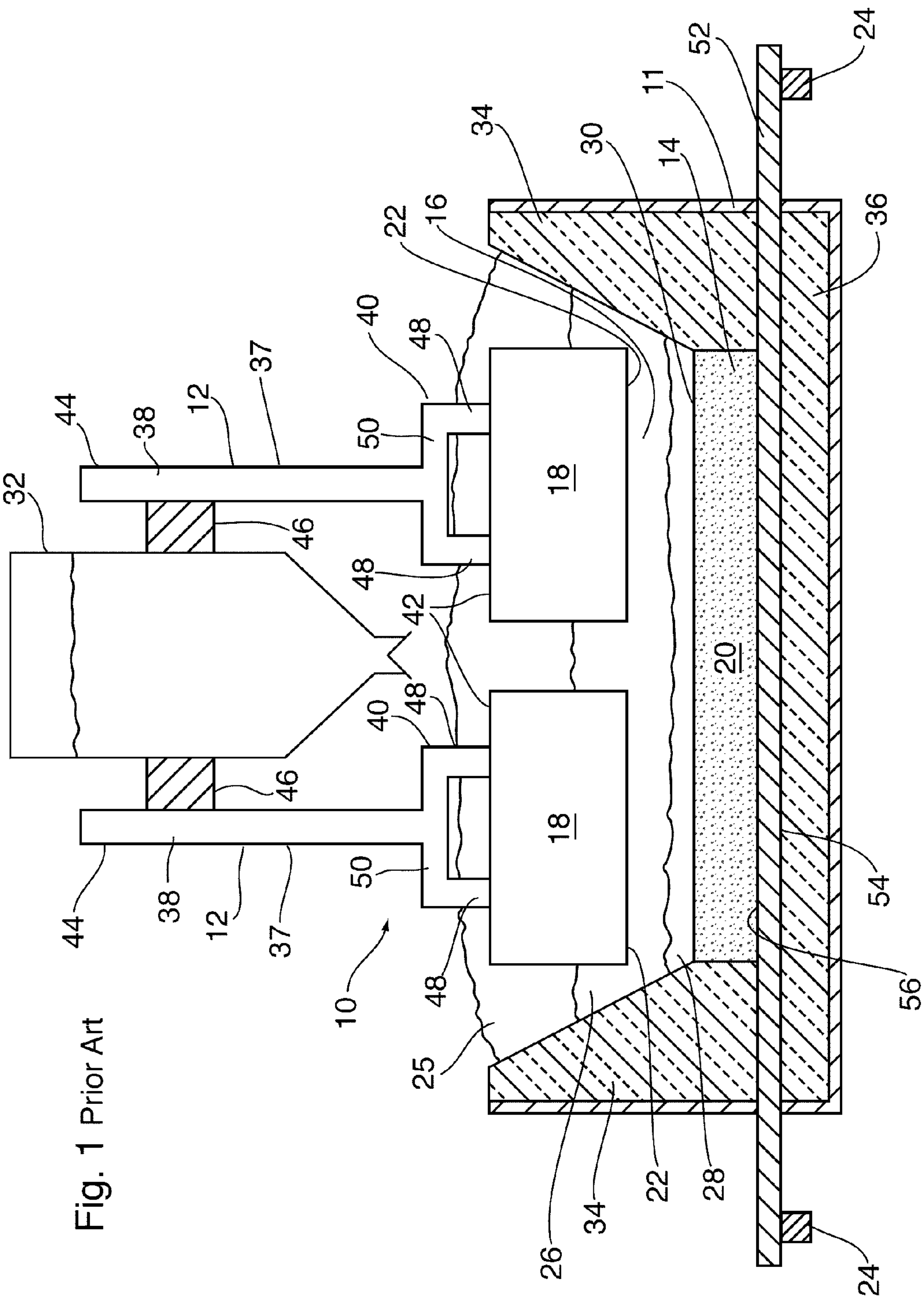

Fig. 1 Prior Art

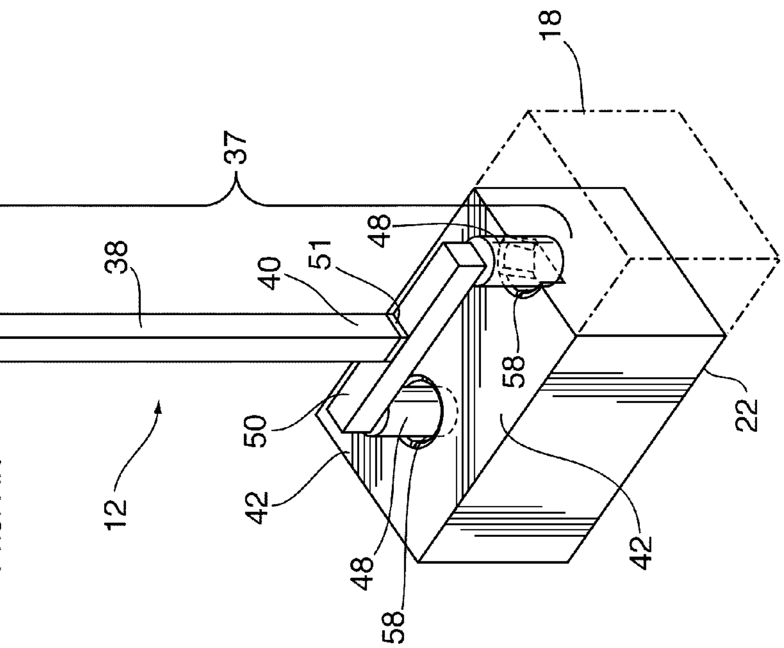

Fig. 3
Prior Art

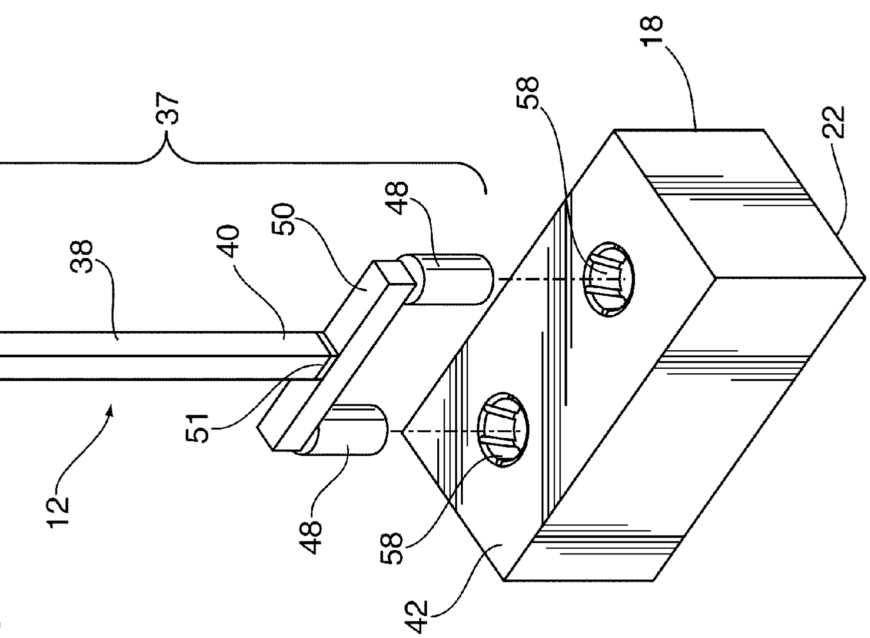

Fig. 2
Prior Art

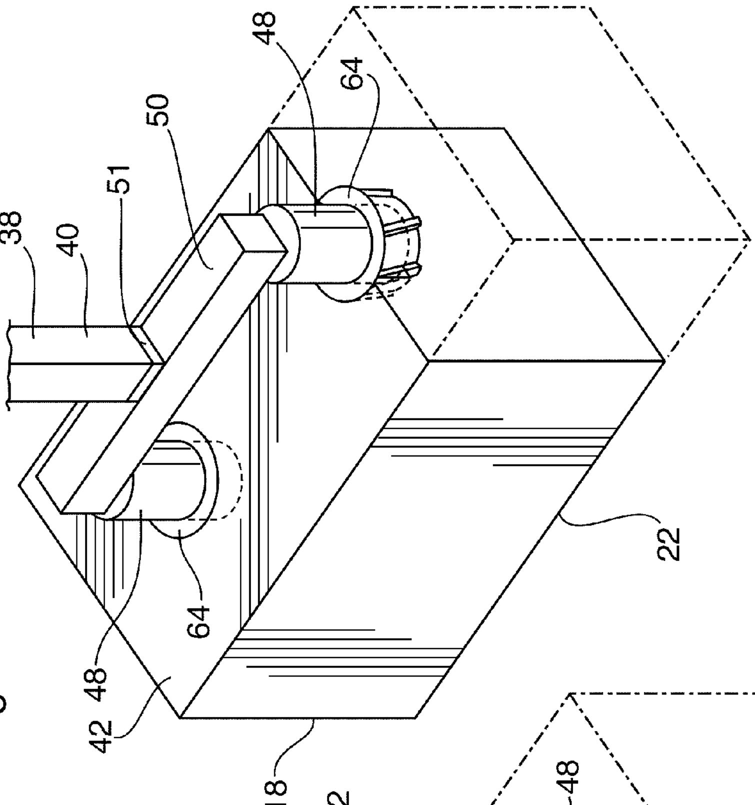

Fig.5 Prior Art

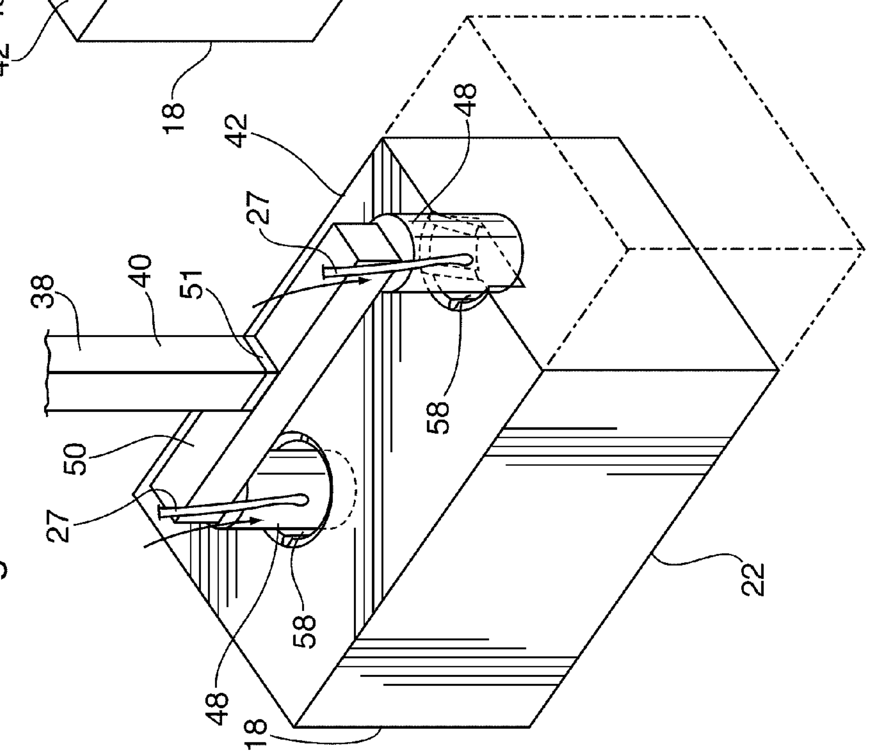

Fig.4 Prior Art

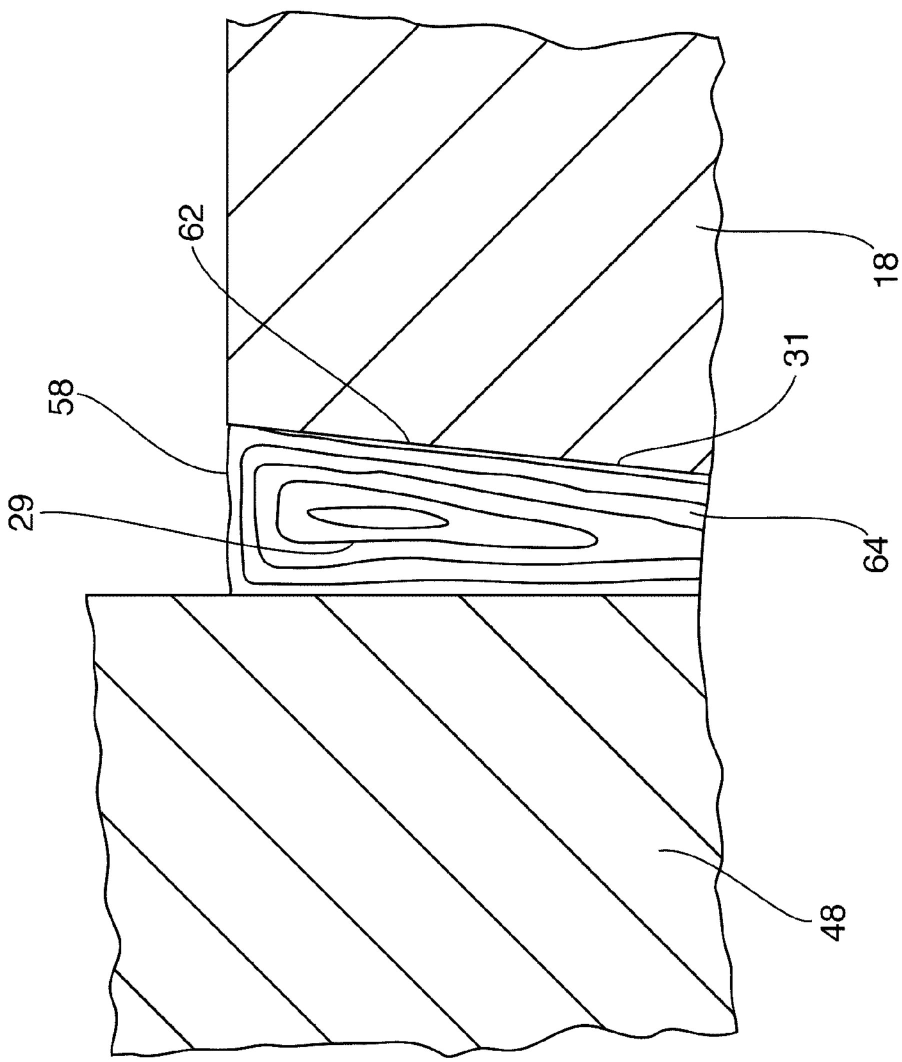

Fig.5a Prior Art

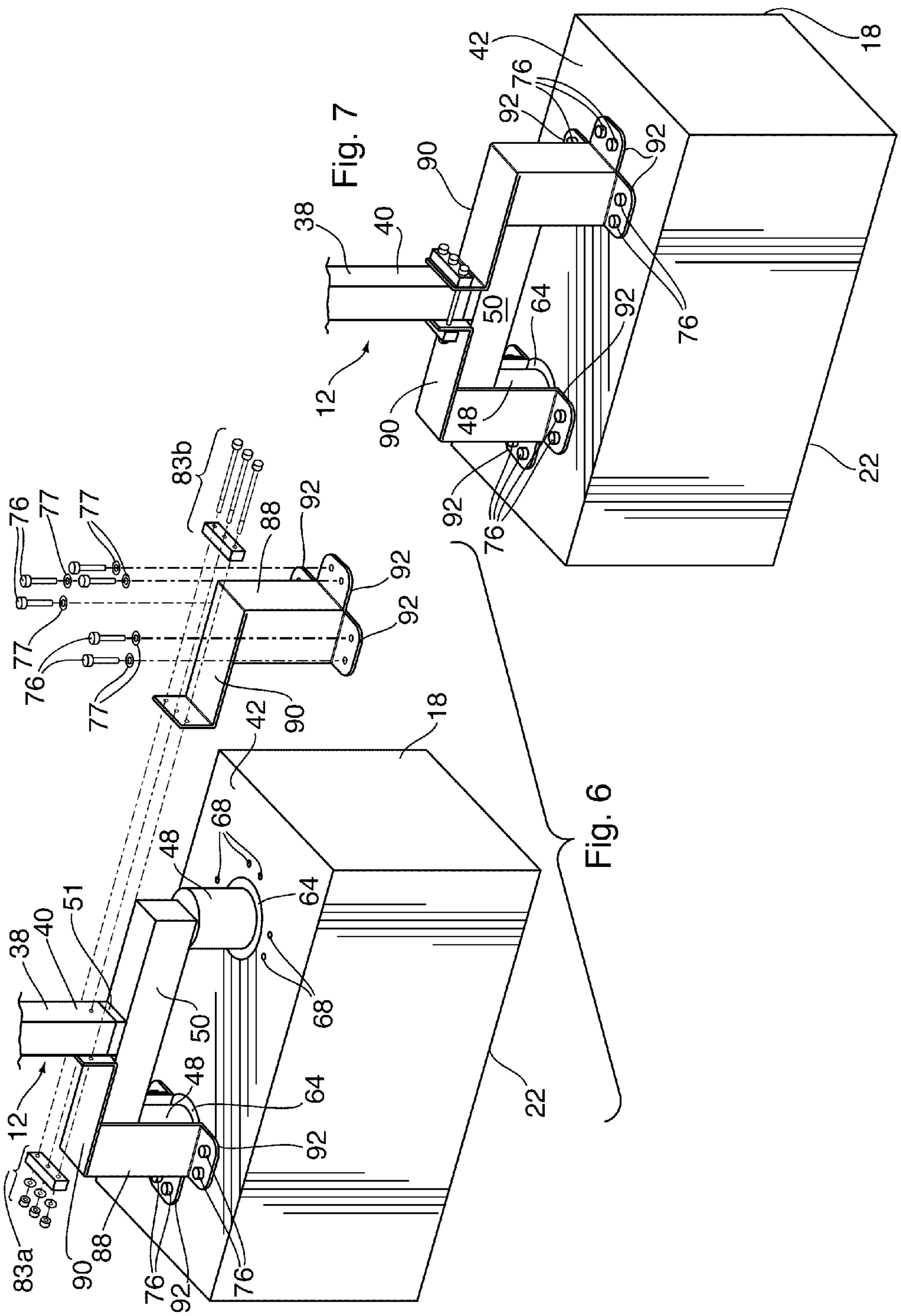

Fig. 6

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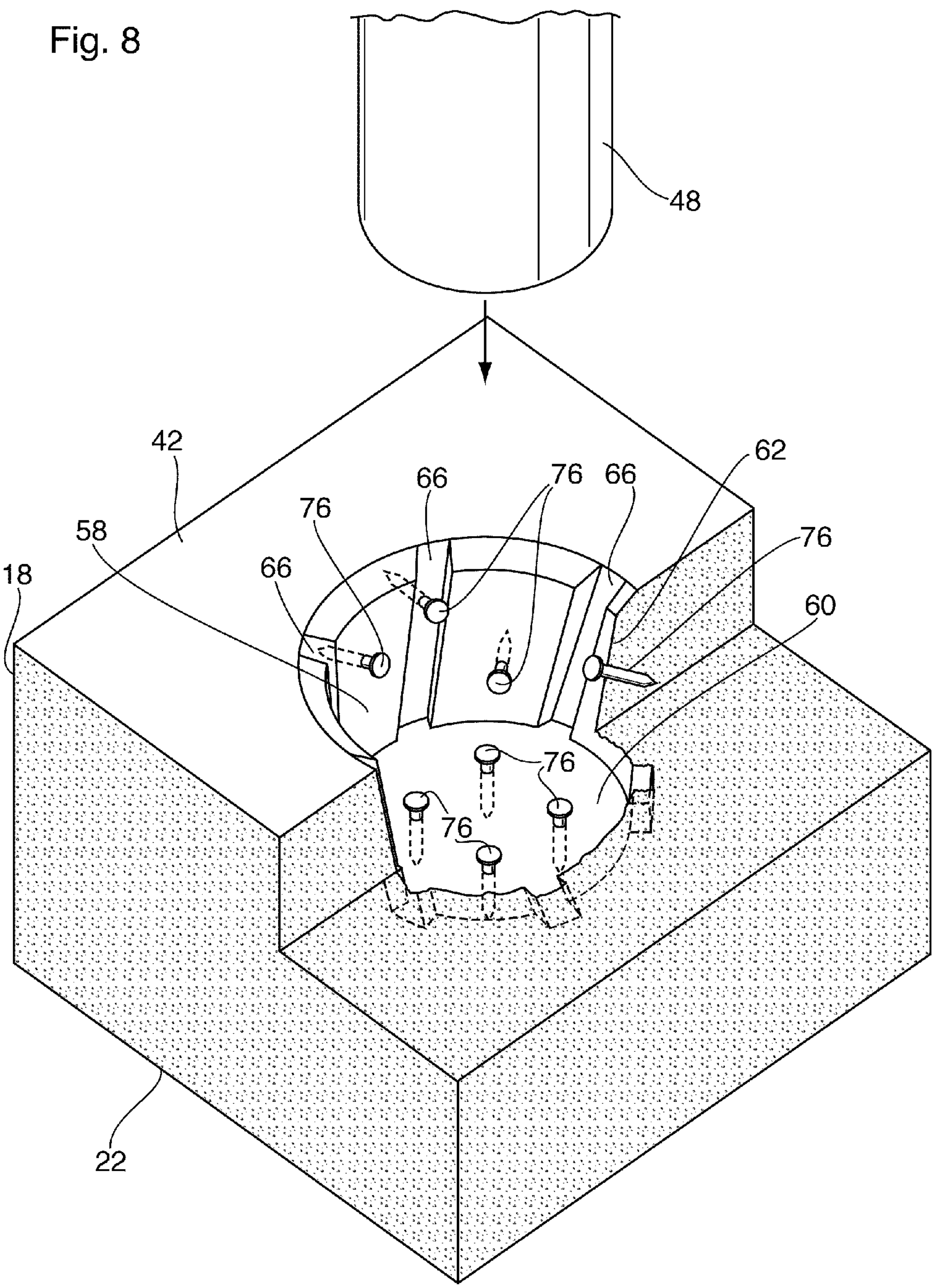

Fig. 8a

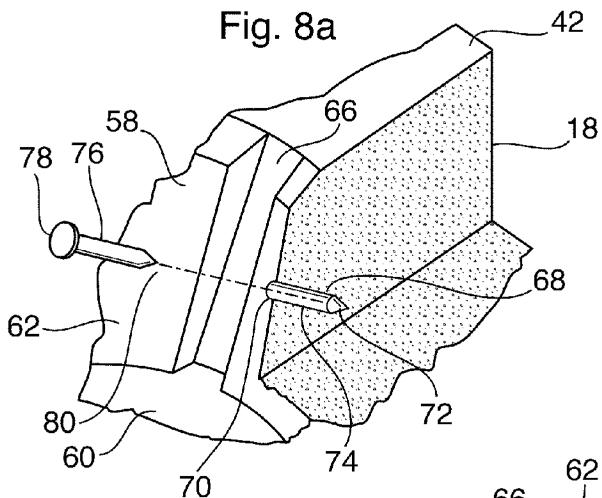
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Fig. 9

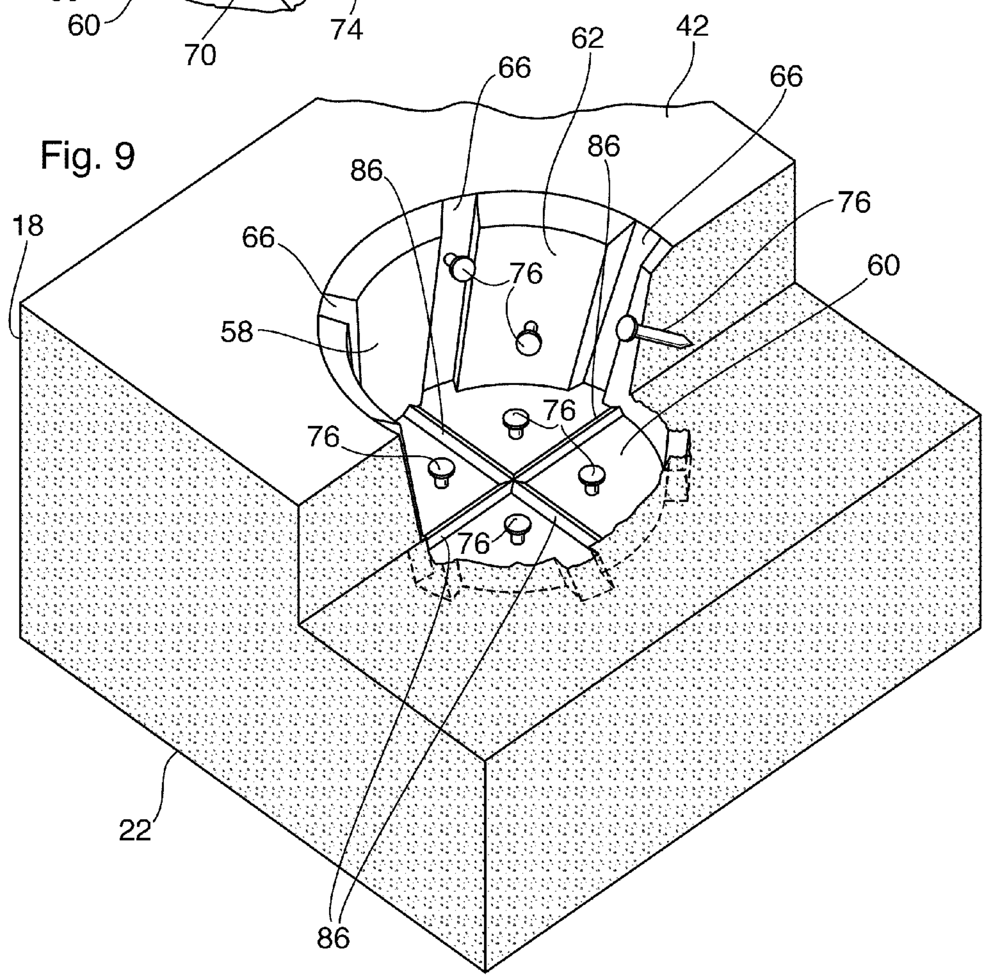
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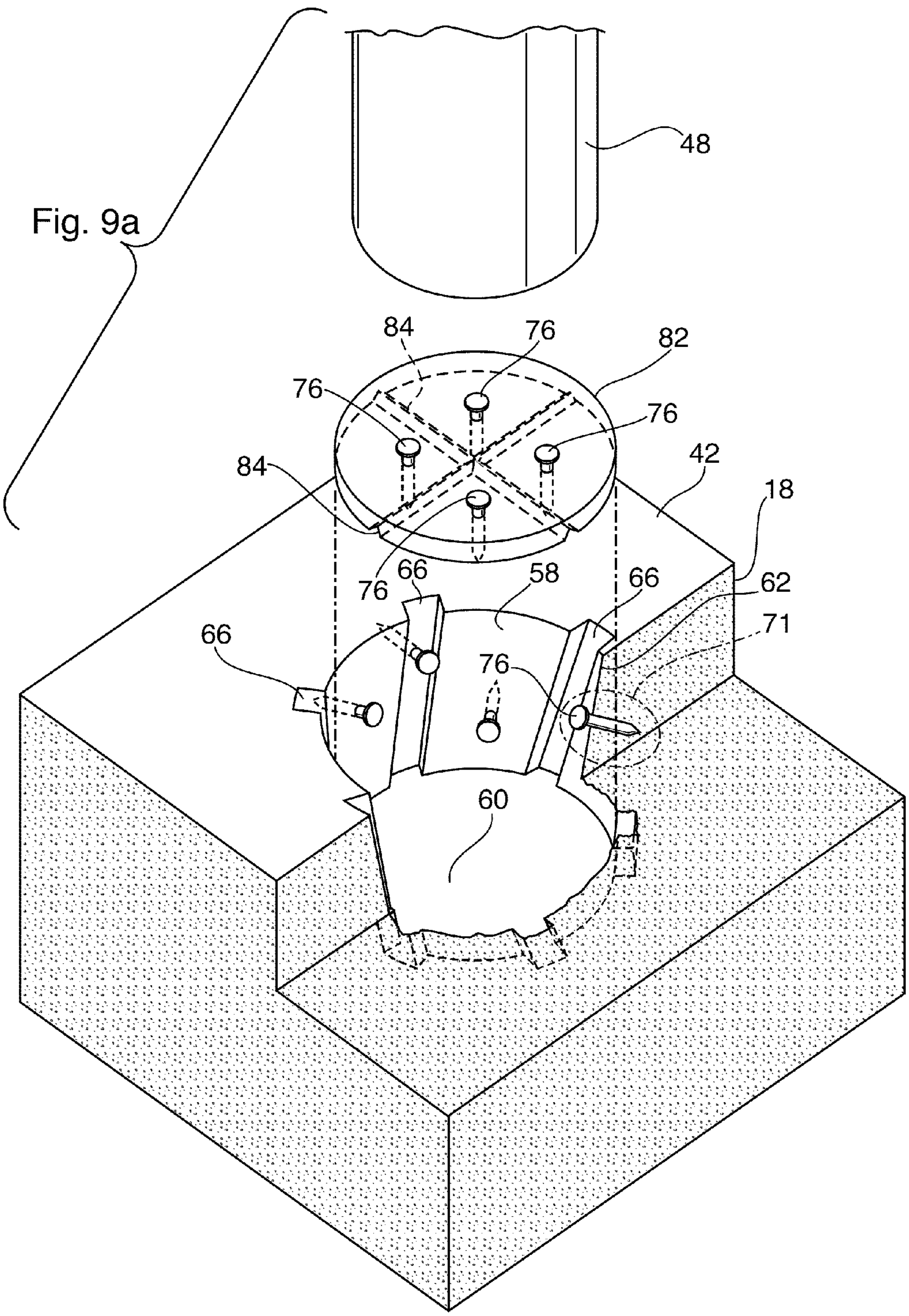
Fig. 9a



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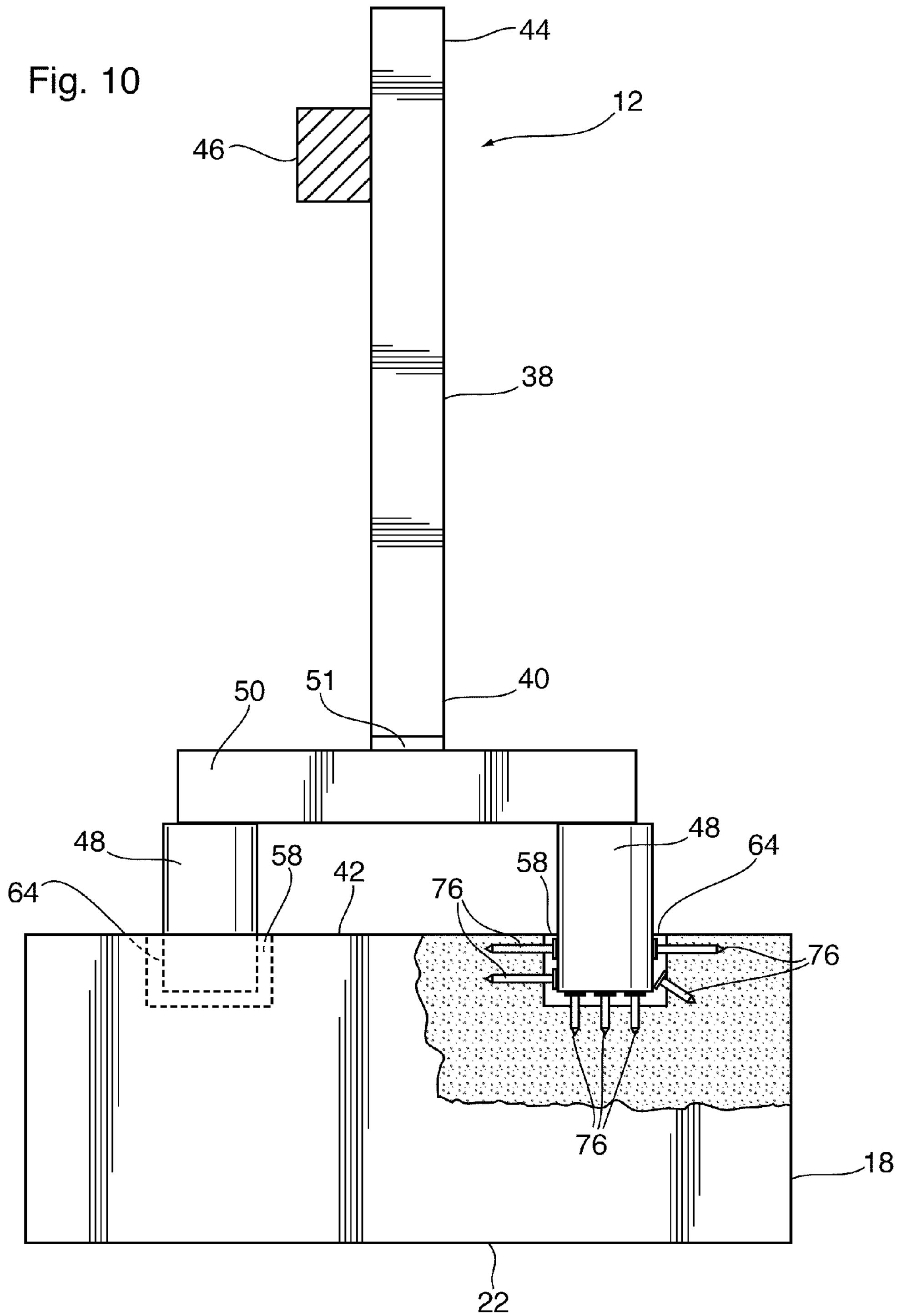

Fig. 11

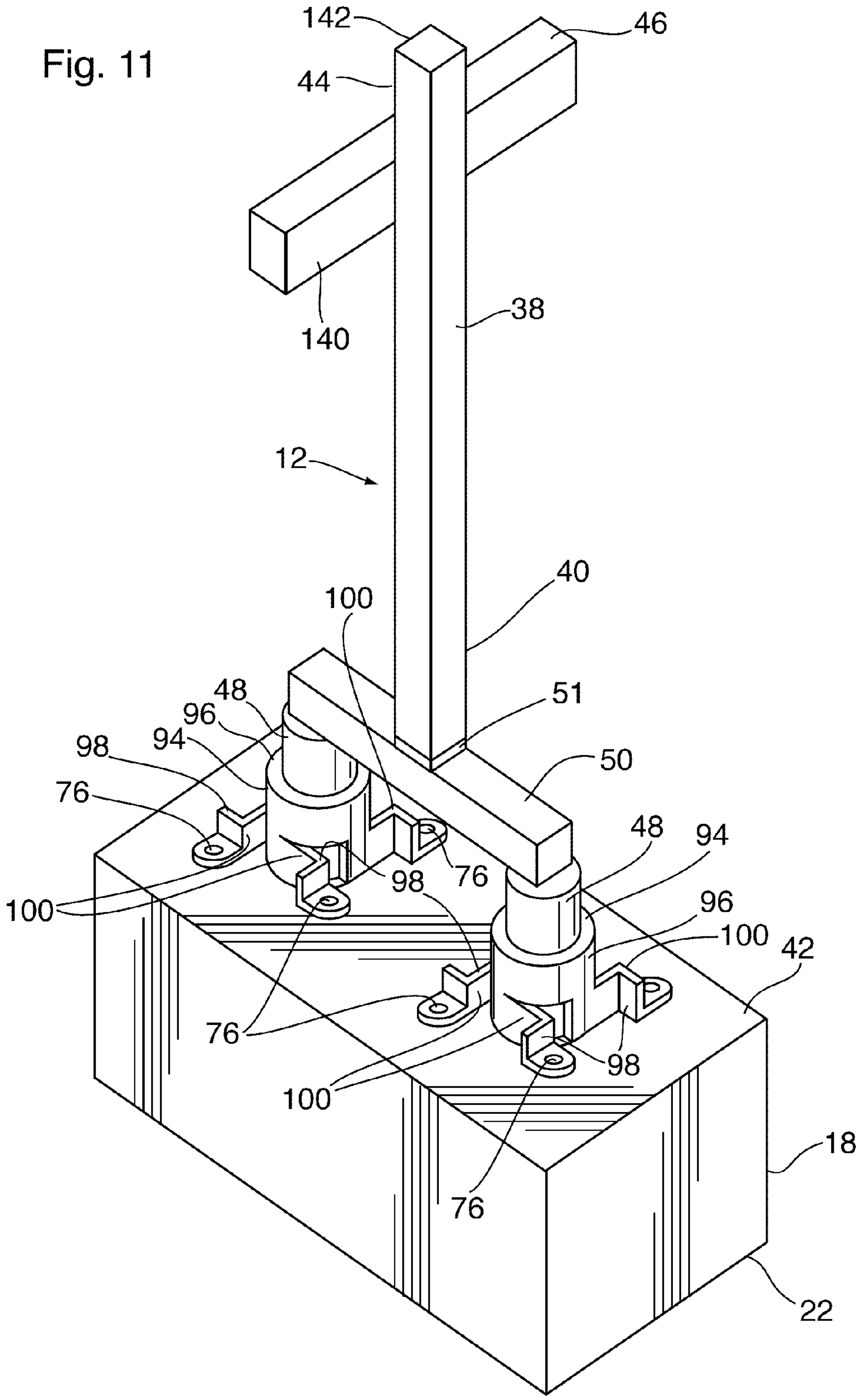
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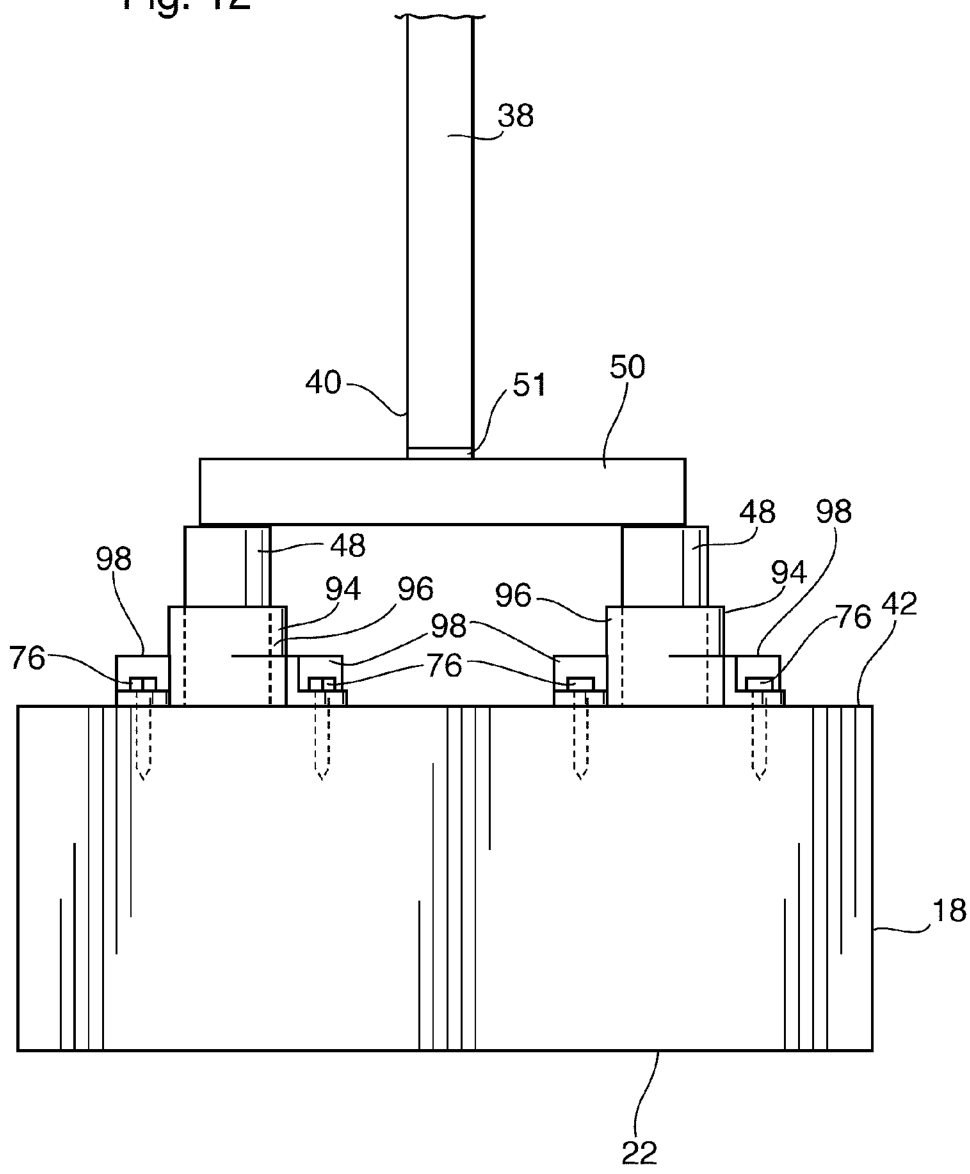
Fig. 12



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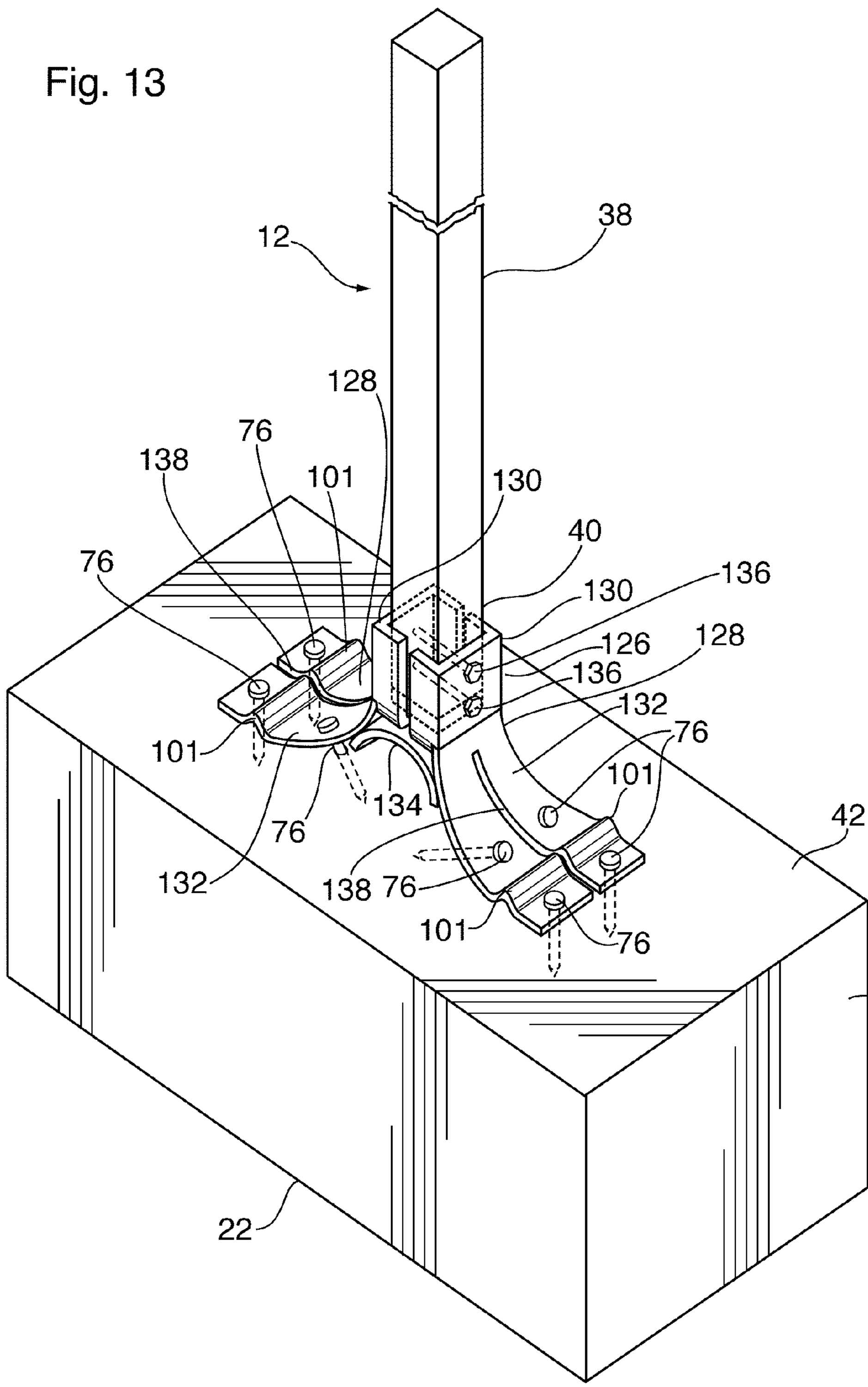

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Fig. 14a

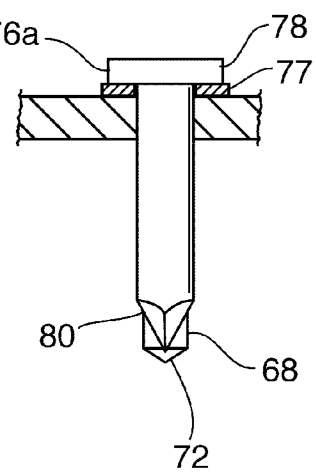


Fig. 14b

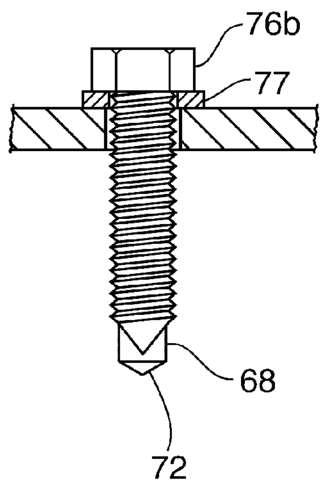


Fig. 14c

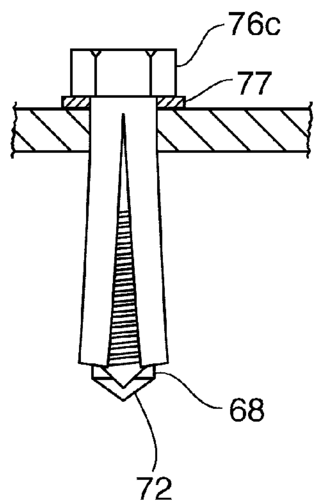
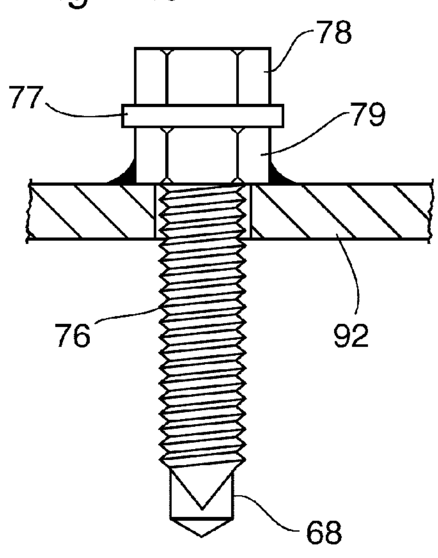


Fig. 14d



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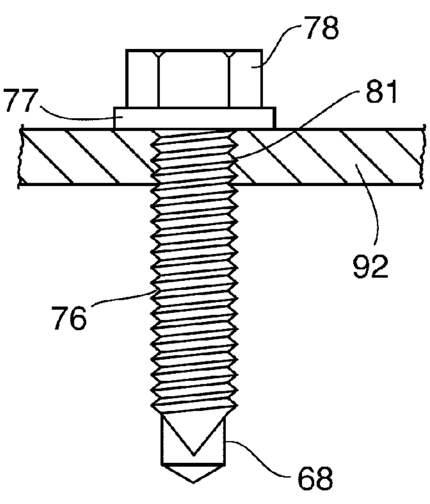


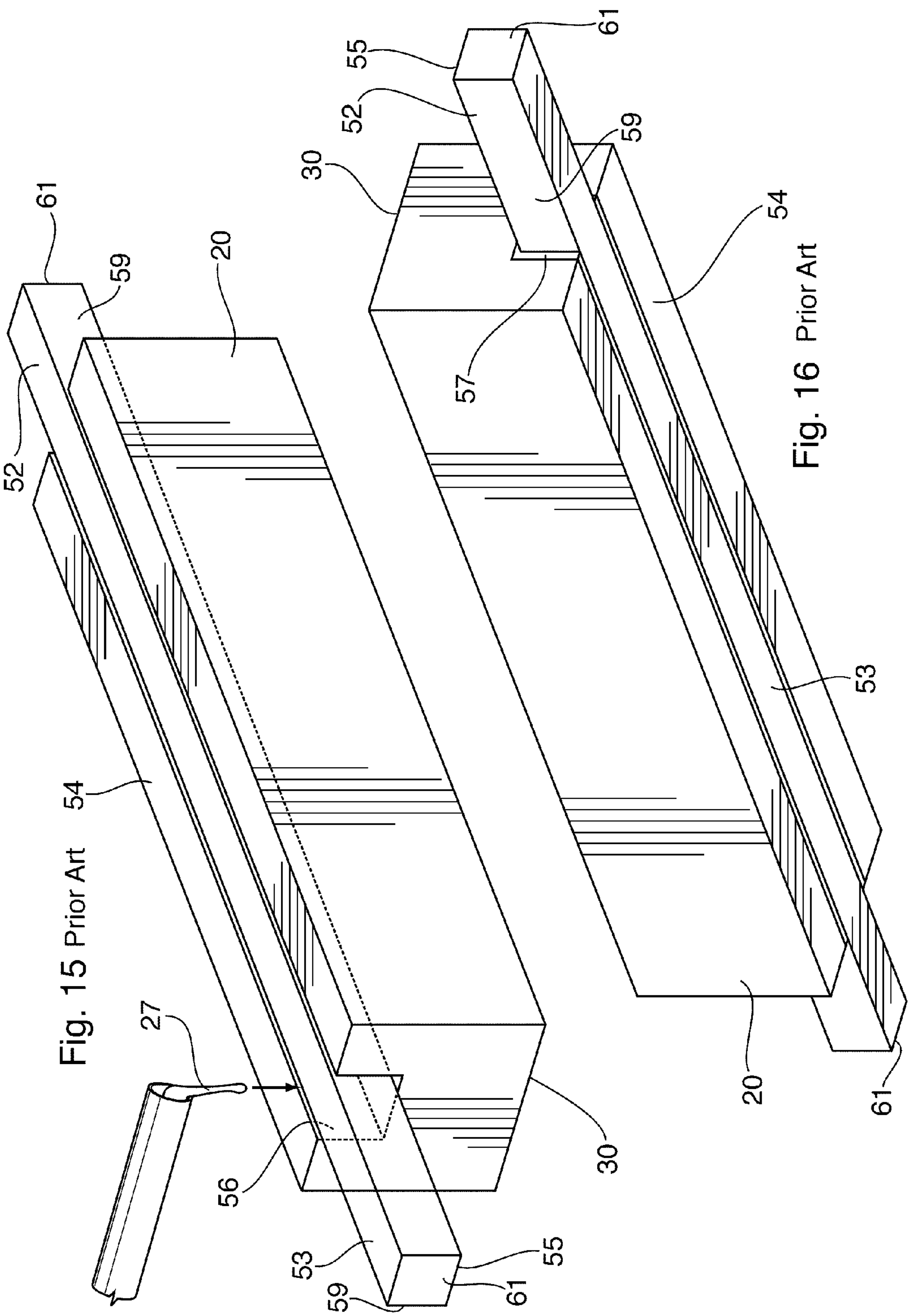


Fig. 15 Prior Art

Fig. 16 Prior Art

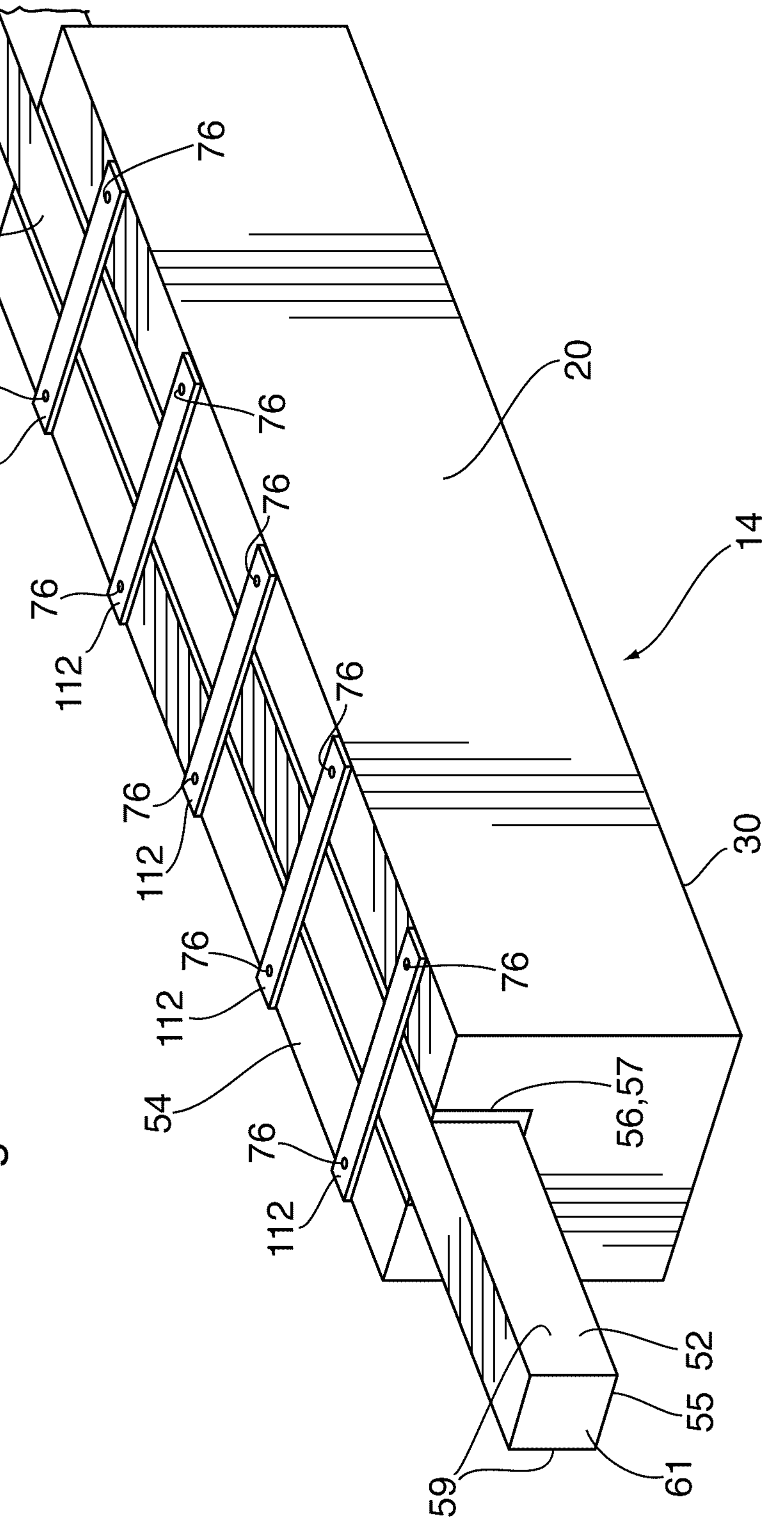
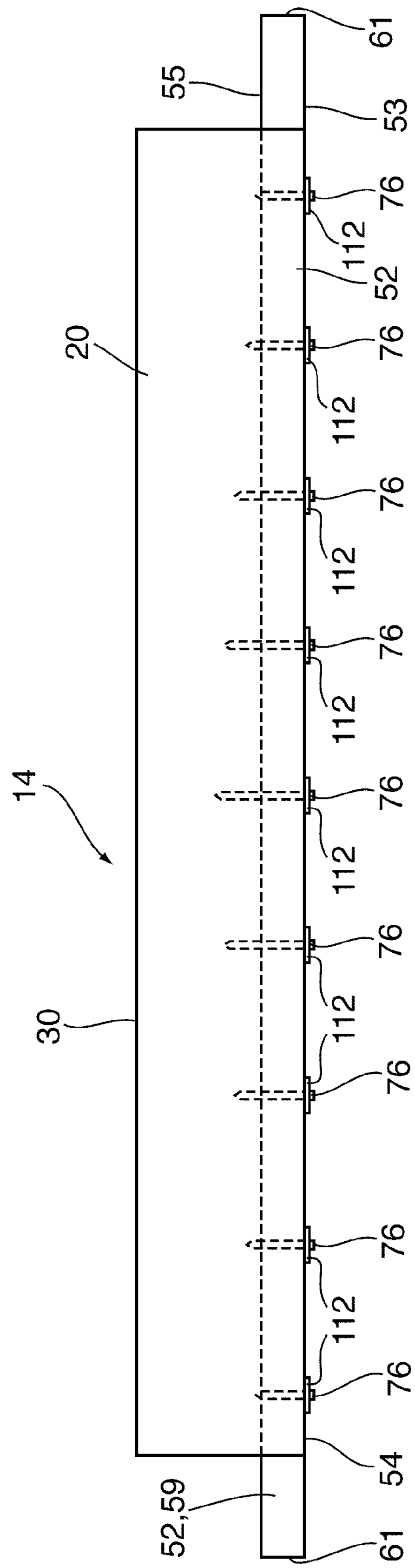
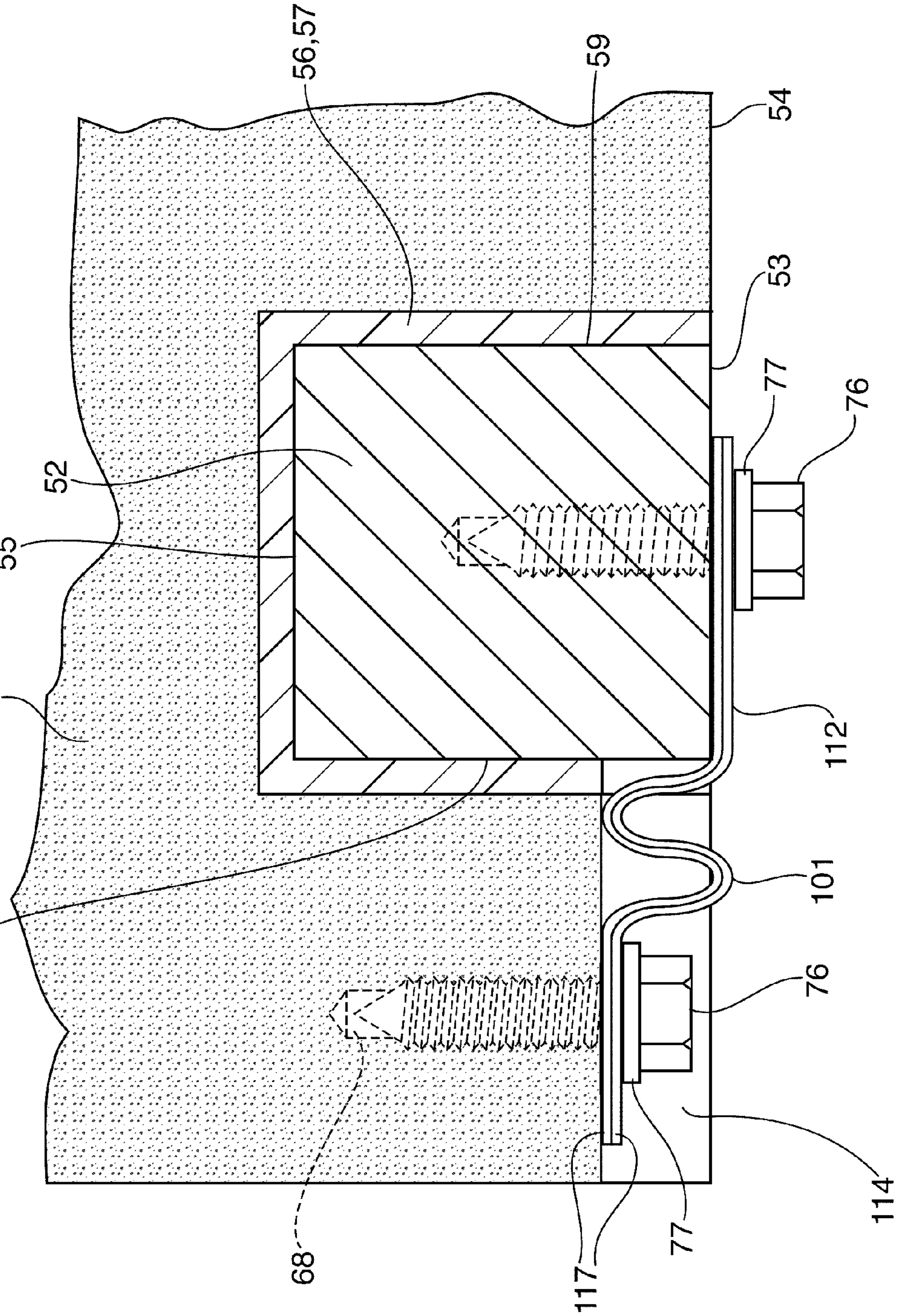


Fig. 17

Fig. 18





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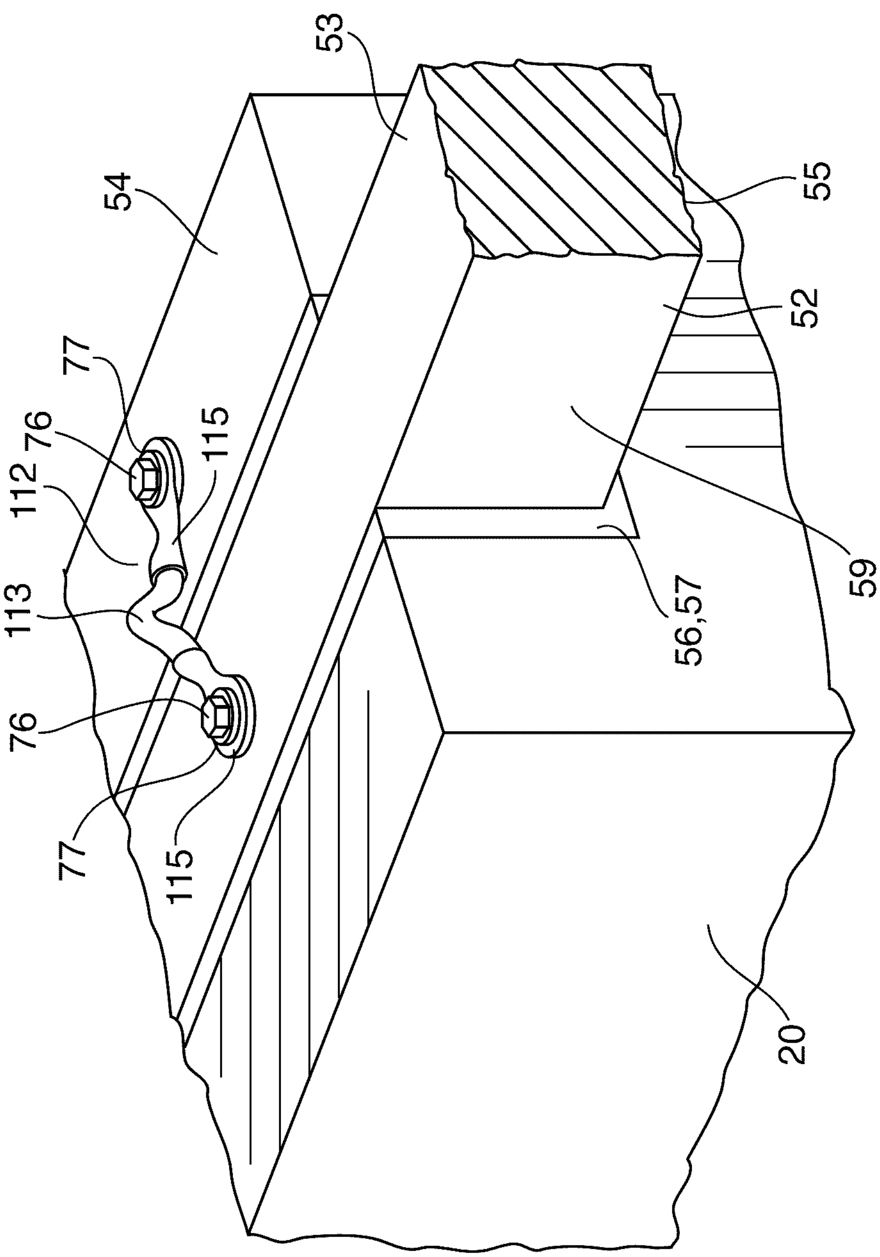
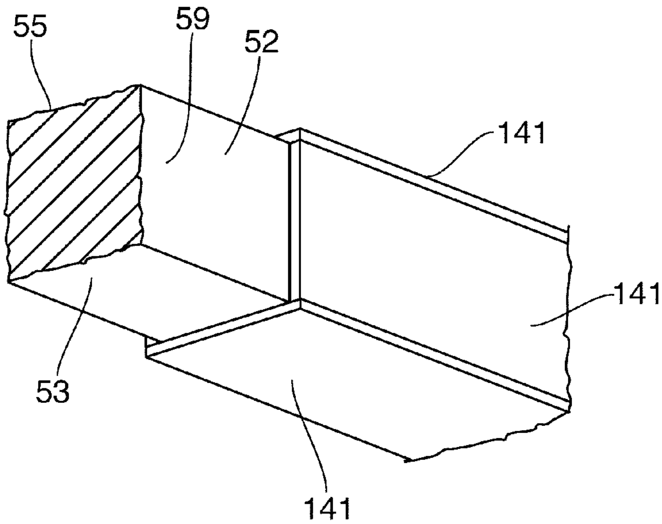


Fig. 20

Fig. 21



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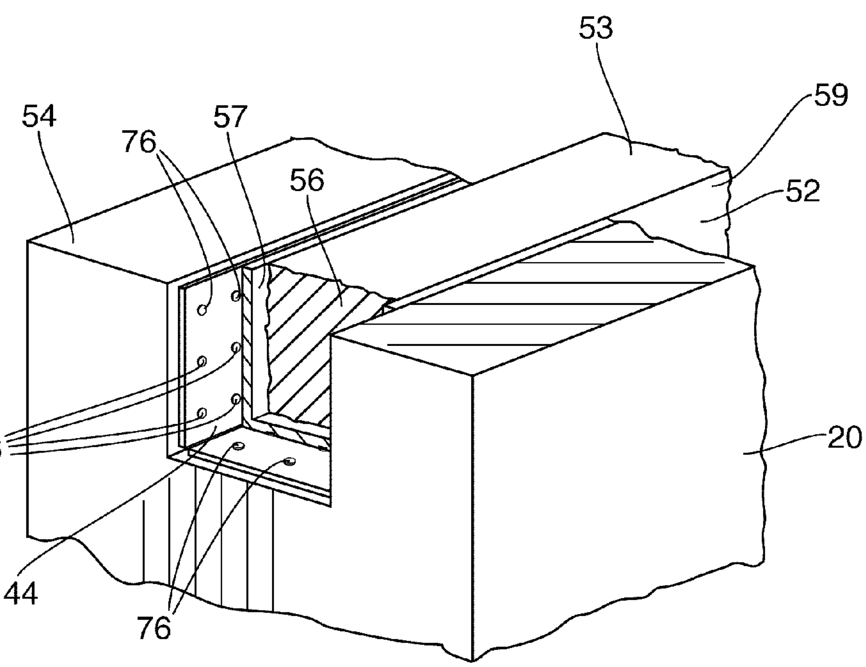

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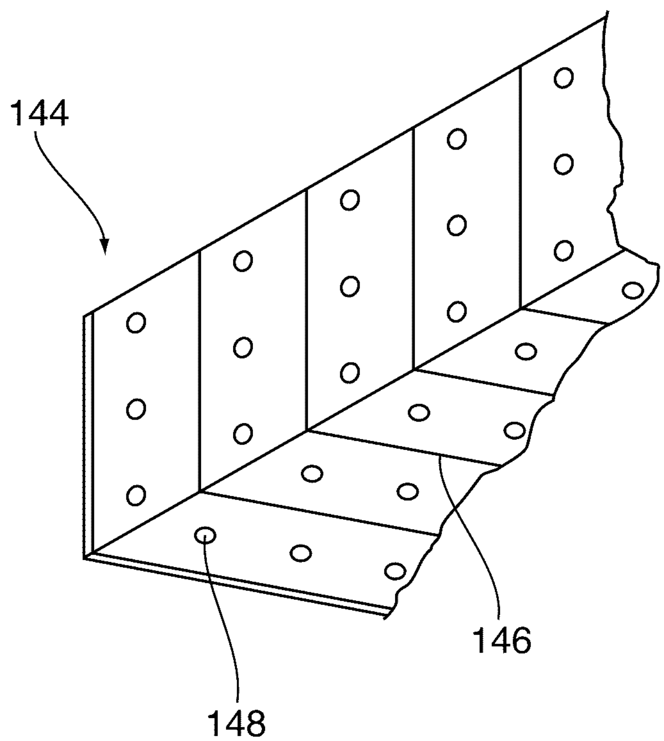

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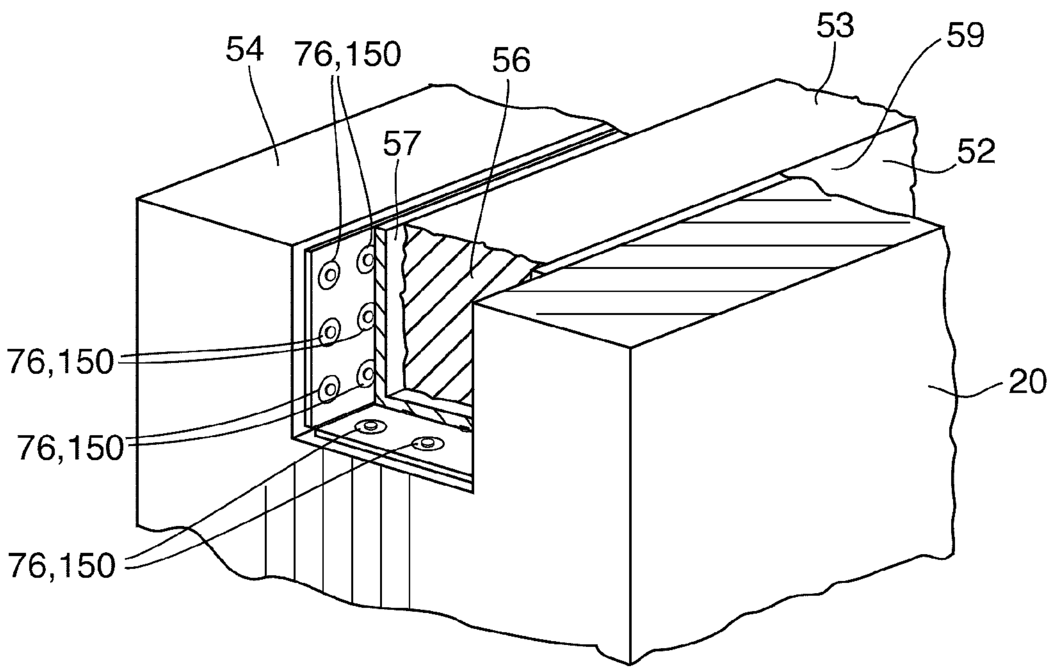

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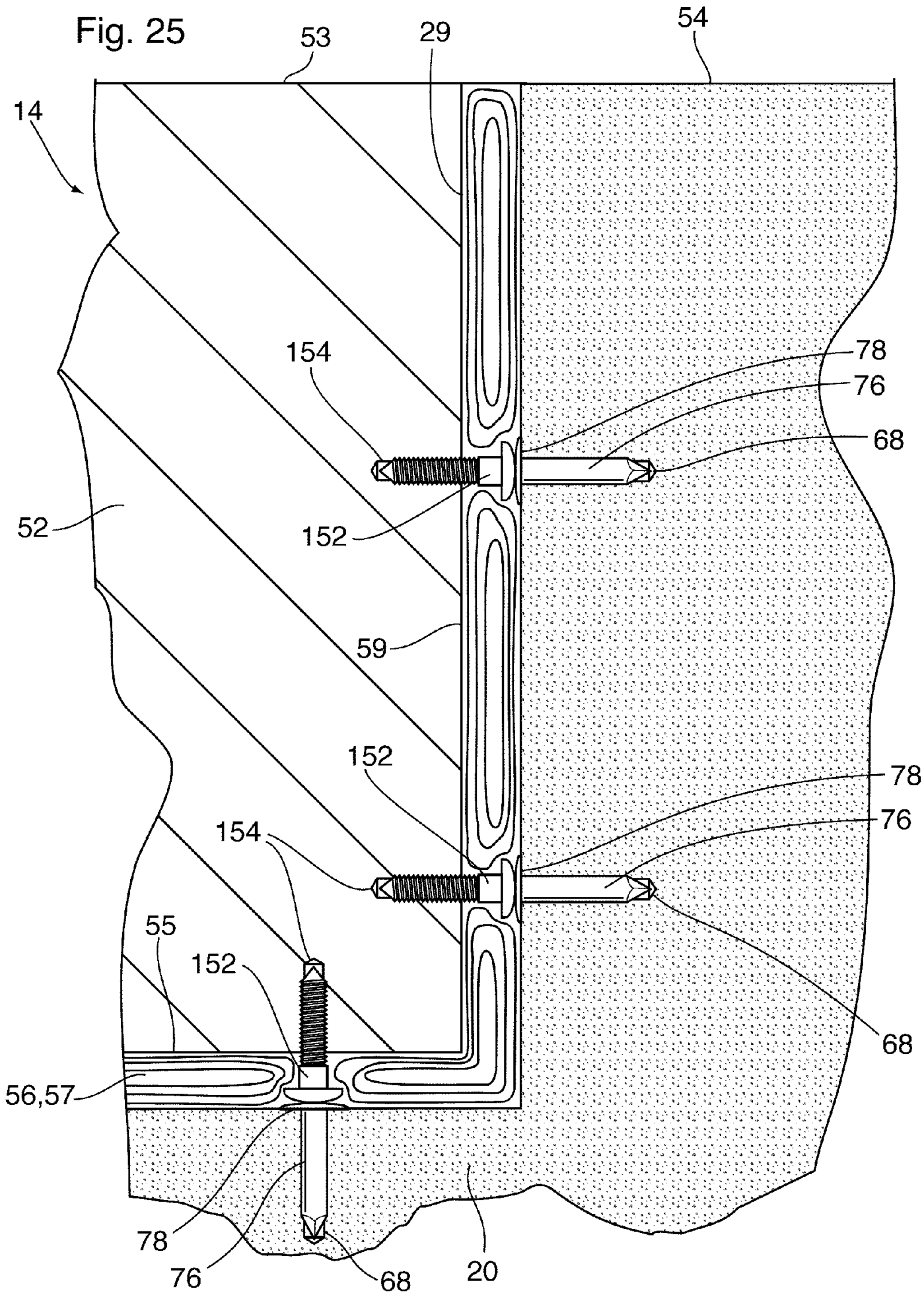
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Fig. 26

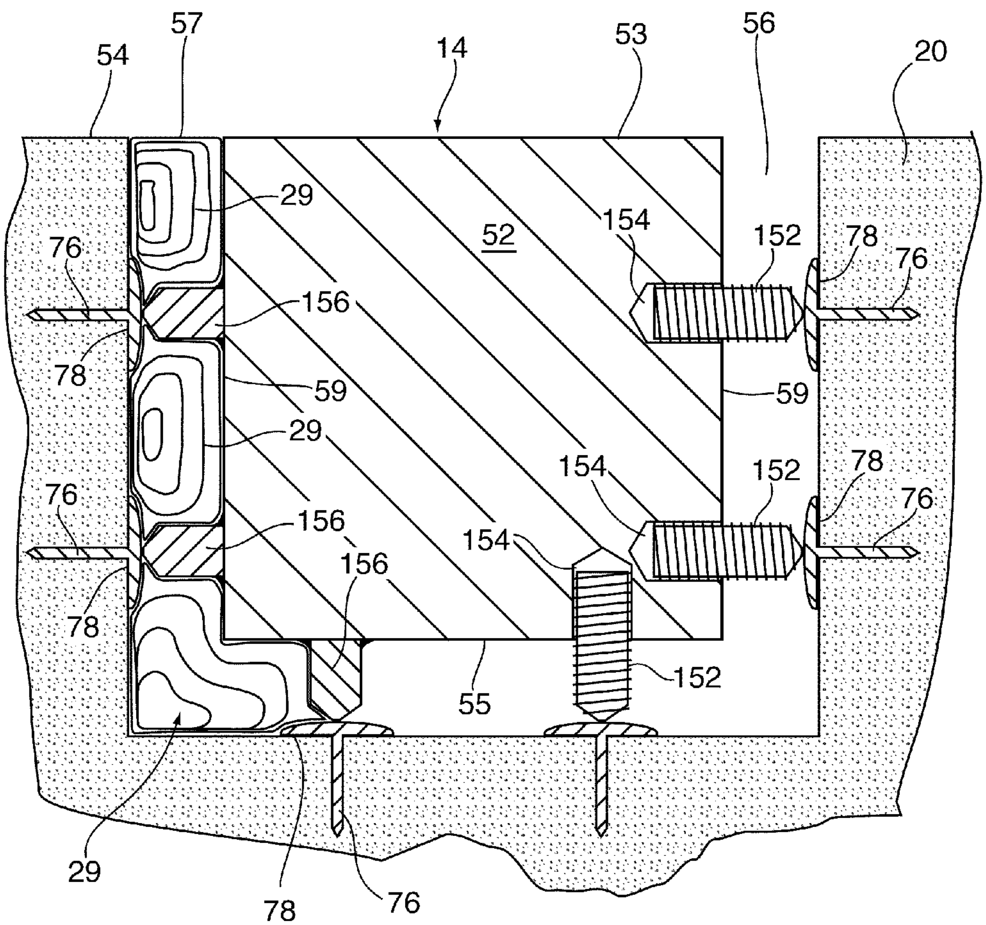

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Fig. 27

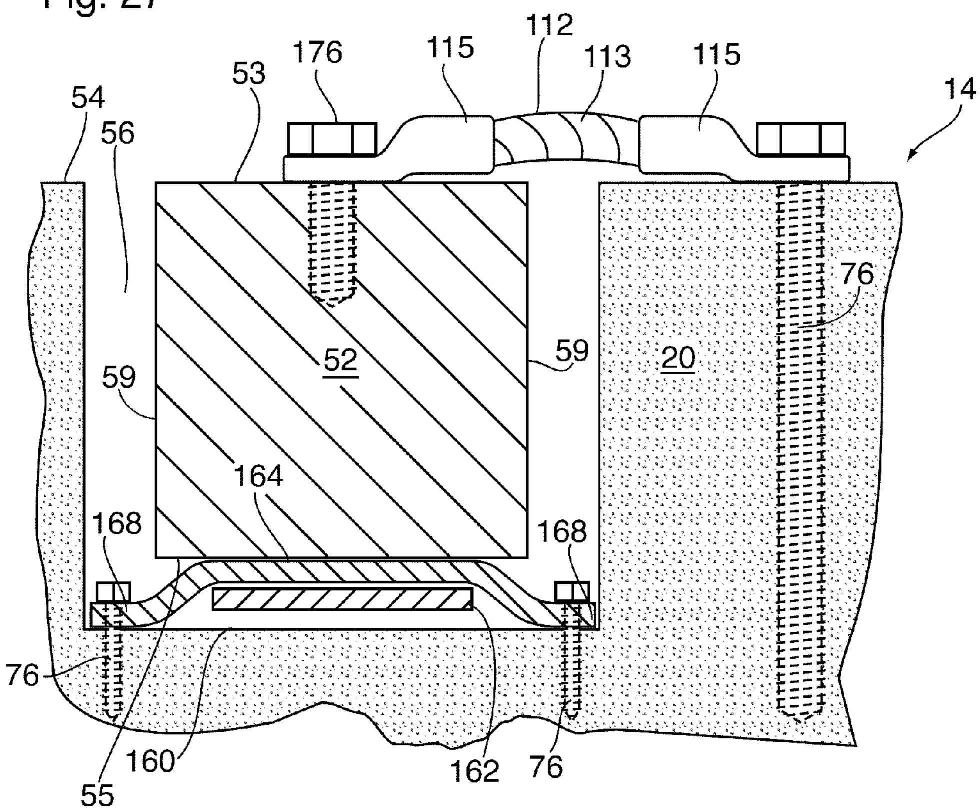

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Fig. 28

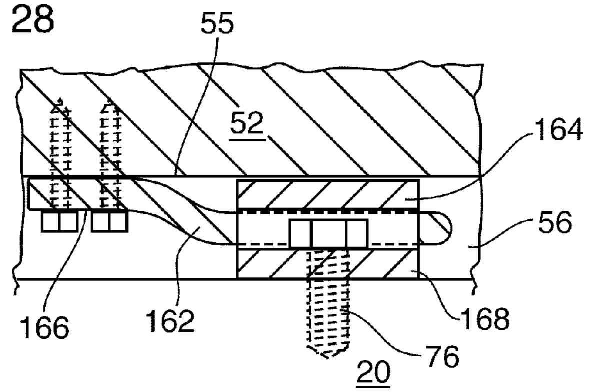

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Fig. 29

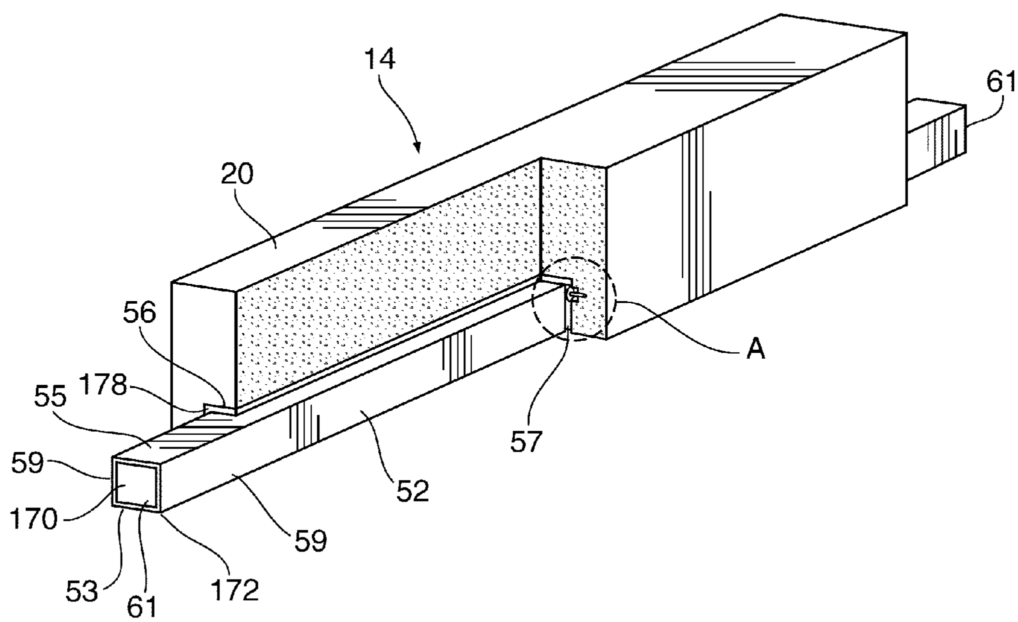


Fig. 30

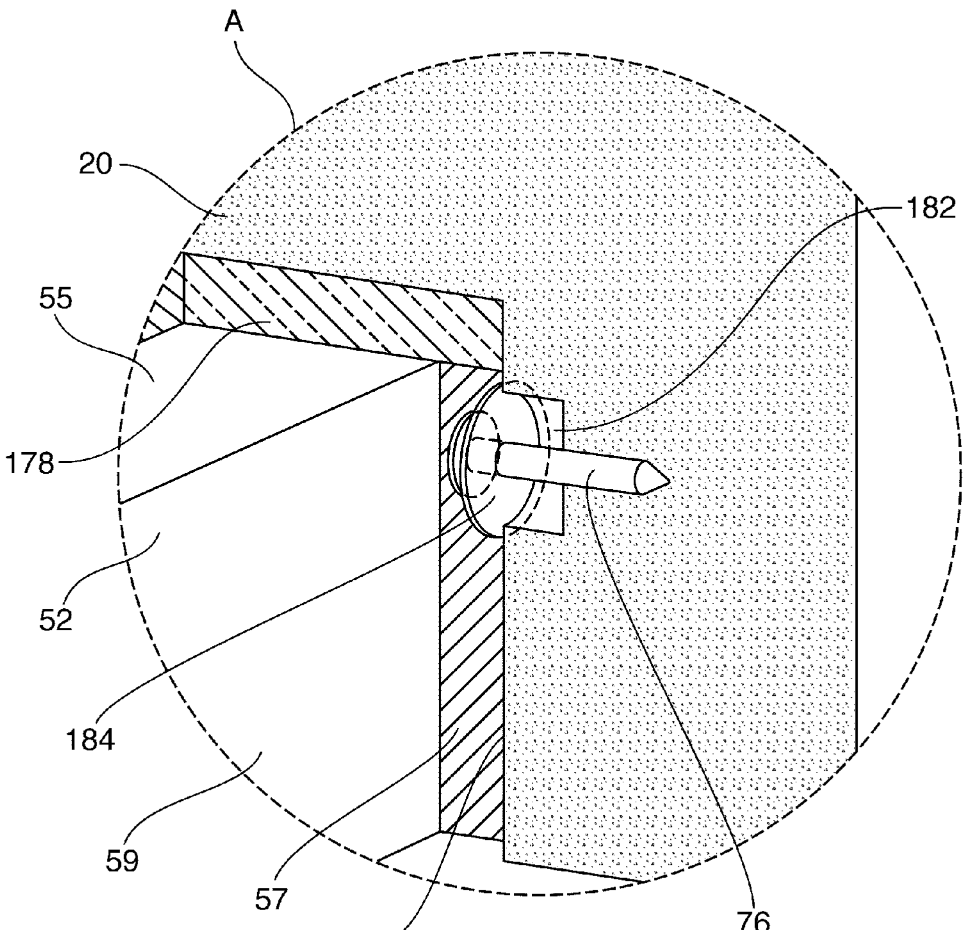


Fig. 31

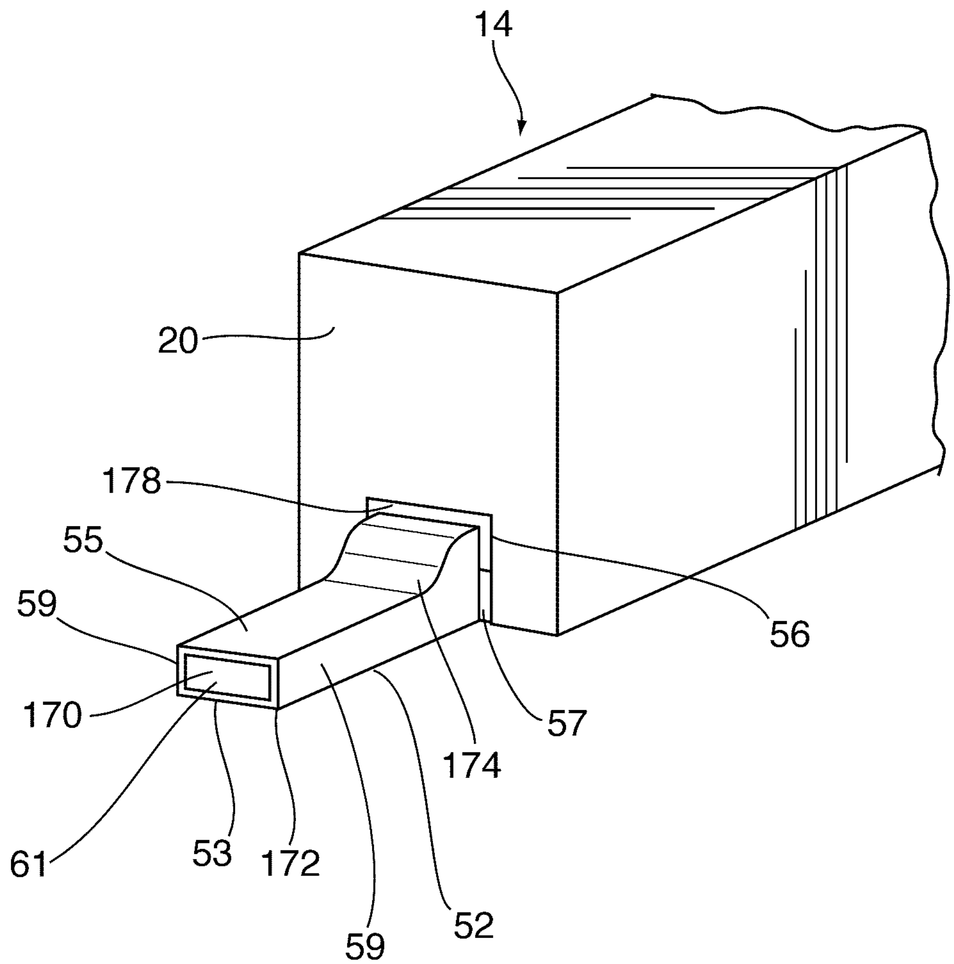


Fig. 32

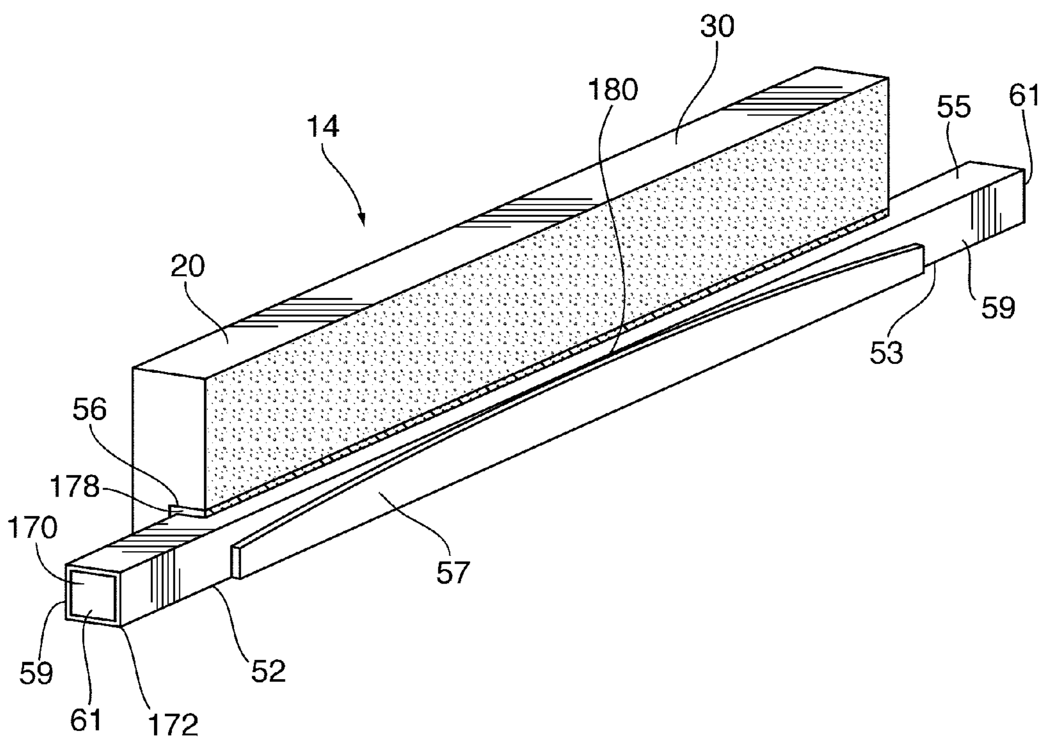


Fig. 33

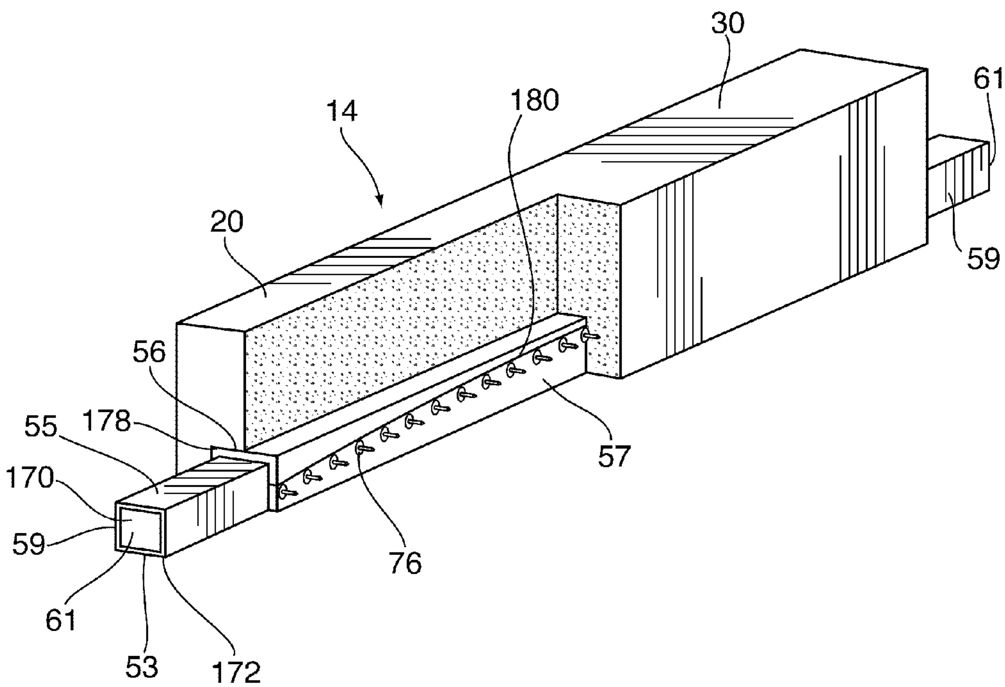


Fig. 34

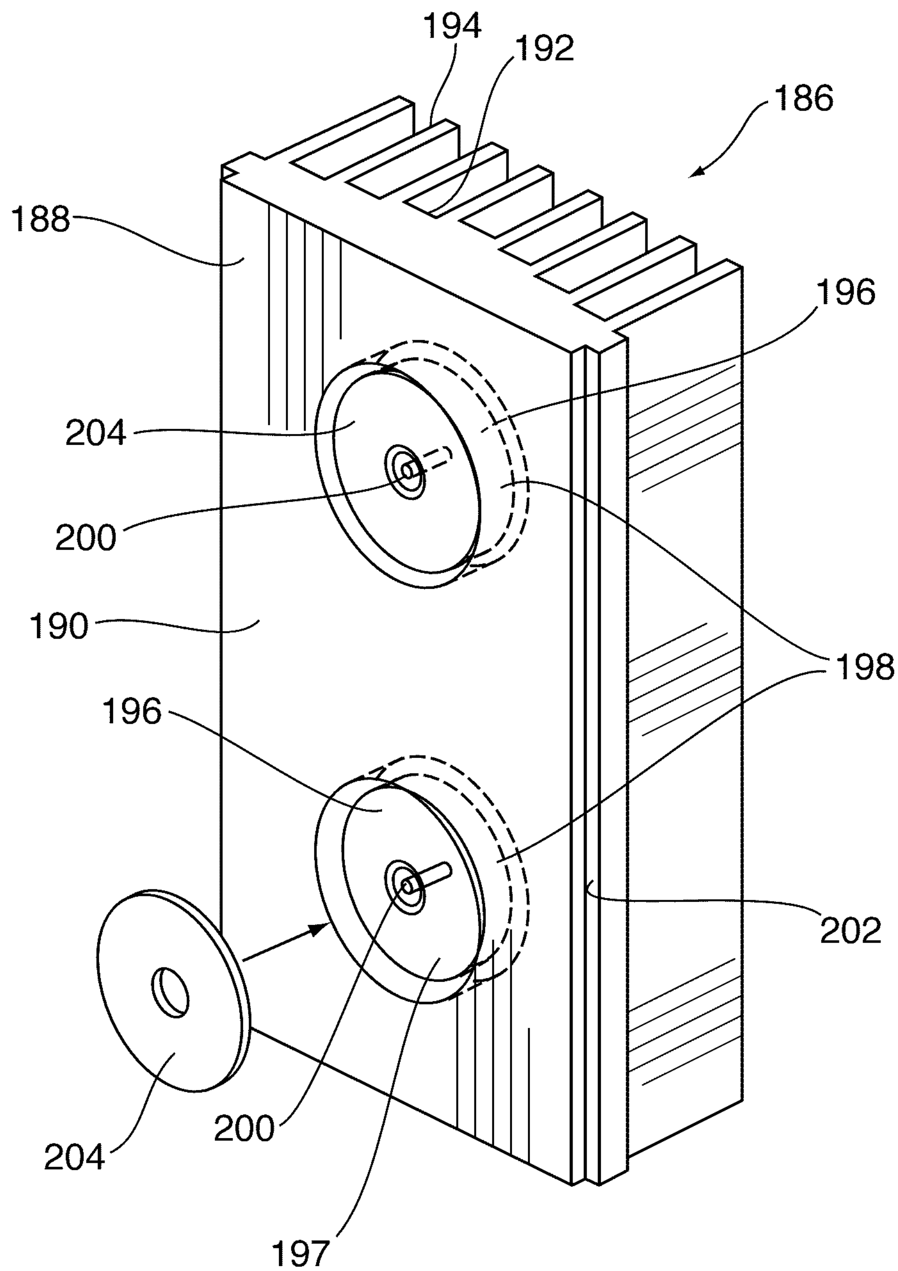
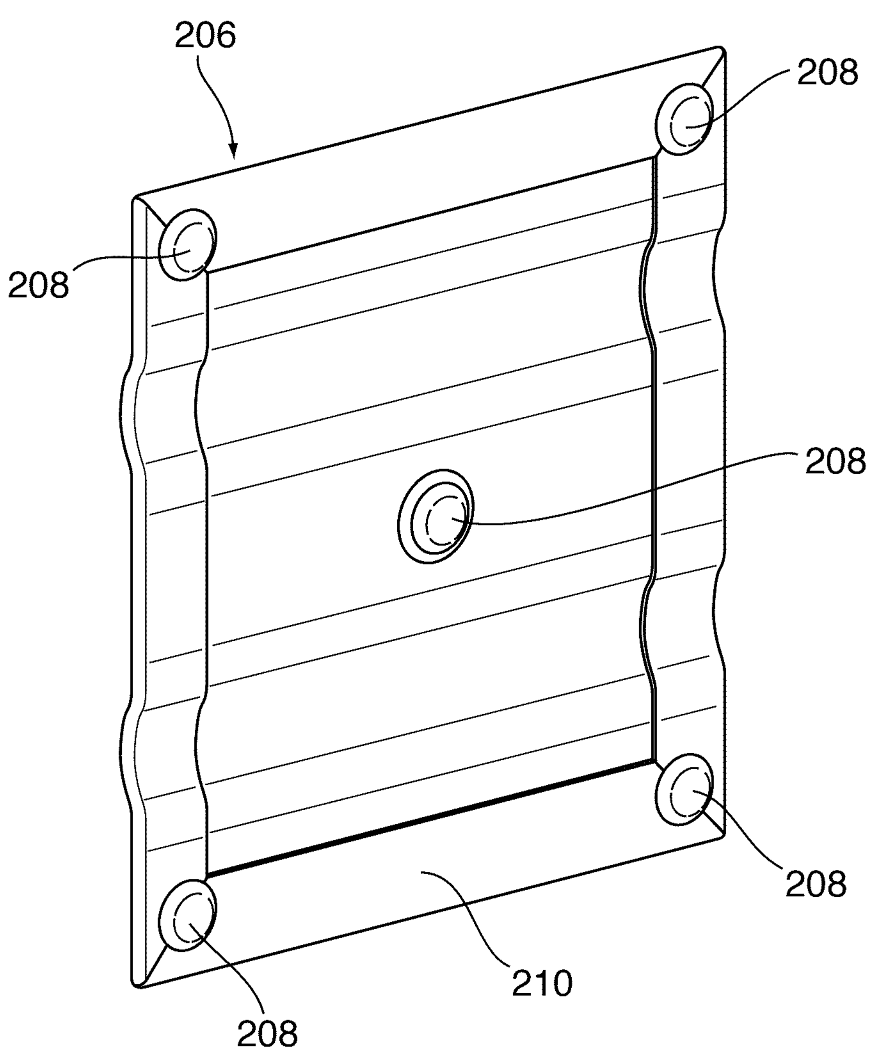


Fig. 35



LOW RESISTANCE ELECTRODE ASSEMBLIES FOR PRODUCTION OF METALS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to and the benefit of Canadian Patent Application No. 2 838 113 filed Dec. 16, 2013 and U.S. Provisional Patent Application No. 62/081,187 filed Nov. 18, 2014, the contents of each are incorporated herein by reference.

TECHNICAL FIELD

[0002] 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

[0003] 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.

[0004] 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.

[0005] 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 U.S. Pat. No. 3,398,081 to Bonfils et al.

[0006] 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.

[0007] 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.

[0008] 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 U.S. Pat. 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. U.S. Pat. No. 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. U.S. Pat. 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. U.S. Pat. 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).

[0009] 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

[0010] 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.

[0011] According to one aspect, the electrode is a prebaked 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.

[0012] 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.

[0013] 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.

[0014] 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.

[0015] 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.

[0016] 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.

[0017] 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.

[0018] 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.

[0019] 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.

[0020] 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.

[0021] 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.

[0022] According to yet another aspect, the insert is received in a bore either pre-drilled or formed in the carbon electrode block.

[0023] 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.

[0024] 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.

[0025] According to yet another aspect, there is provided a magnetic mounted cooling fin for removable attachment to a steel potshell of a reduction cell for the production of metal. The magnetic mounted cooling fin comprises: (a) a bottom plate having a bottom surface and a top surface, wherein the bottom surface is adapted to be received against the potshell; (b) one or more fins extending from the top surface of the bottom plate; (c) one or more magnets having a curie point of at least about five hundred degrees Celsius, said one or more magnets being secured to said bottom plate.

[0026] According to yet another aspect, the magnets of the magnetic mounted cooling fin may comprise rare earth magnets and/or non-ferrous magnets. For example, the magnets may comprise Samarium-Cobalt or Aluminum-Nickel-Cobalt (Alnico) alloyed magnets.

[0027] According to yet another aspect, the magnetic mounted cooling fin may further comprise a thermal break attached to the bottom surface of the magnet, situated between the magnet and the potshell, wherein the thermal break comprises a thin layer of a non flammable material with low thermal conductivity.

[0028] According to yet another aspect, there is provided a magnetic mounted blanket for removable attachment to a steel potshell of a reduction cell for the production of metal. The magnetic mounted blanket comprises: (a) one or more layers of a flexible, high temperature resistant material having a melting point of at least about 600 degrees Celsius; and (b) a plurality of magnets are attached to said material to hold the blanket to the potshell.

[0029] According to yet another aspect, the magnets of the magnetic mounted blanket have a curie point and holding power such that they lose adequate holding power at a predetermined temperature which corresponds to an unacceptably high temperature of said steel potshell. The magnets may be comprised of a ferrous, or nonferrous or rare earth alloy.

[0030] According to yet another aspect, the material of the magnetic mounted blanket may comprise flexible glass or ceramic fibre cloth.

BRIEF DESCRIPTION OF THE DRAWINGS

[0031] In order that the claimed subject matter may be more fully understood, reference will be made to the accompanying drawings, in which:

[0032] FIG. **1** is a cross section through a prior art reduction cell;

[0033] FIGS. **2** and **3** are perspective views showing the stubs of a prior art anode assembly before and after insertion into the stub holes of the anode block;

[0034] FIGS. **4** and **5** are perspective views showing the casting of the thimble in the prior art anode of FIGS. **2** and **3**;

[0035] FIG. **5***a* is an enlarged, partial vertical cross-sectional view through the stub, thimble and anode block of the prior art anode of FIG. **5**;

[0036] FIGS. **6** and **7** are perspective views showing the electrode of FIG. **5** provided with electrically conductive bypass members;

[0037] FIG. **8** is a partial, perspective cross-sectional view, showing a recess for receiving a stub according to an embodiment described herein;

[0038] FIG. **8***a* is a close-up, cut-away view of an insert embedded in the wall of the stub hole shown in FIG. **8**;

[0039] FIG. **9** is a partial, perspective cross-sectional view, showing a recess for receiving a stub according to another embodiment described herein;

[0040] FIG. **9***a* shows a preform for formation of a thimble according to an embodiment described herein;

[0041] FIG. **10** is a cut-away side elevation view showing an electrode with thimble anchors;

[0042] FIGS. **11** and **12** show an electrode assembly including an assembly for attaching the stubs to the top surface of the anode block;

[0043] FIG. **13** is a perspective view of an electrode assembly having a low resistance yoke assembly as described herein;

[0044] FIGS. **14***a* to **14***e* are side views of various types of conductive inserts and connections as described herein;

[0045] FIGS. **15** and **16** are perspective views showing the casting of a cast iron layer in a prior art cathode assembly;

[0046] FIG. **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;

[0047] FIG. **18** is a side view of the cathode block of FIG. **17**;

[0048] FIG. **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;

[0049] FIG. **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;

[0050] FIG. **21** is a perspective view of a steel cathode collector bar with a conductive metal surface cladding;

[0051] FIG. **22** is a partial view of the slot of a cathode assembly according to an embodiment disclosed herein;

[0052] FIG. **23** is a perspective view showing a portion of a conductive lining for a cathode slot;

[0053] FIG. **24** is a partial view of the slot of a cathode assembly according to another embodiment disclosed herein;

[0054] FIGS. **25** to **28** are views of cathode assemblies, showing alternate methods for connecting the current collector bar to the cathode block;

[0055] FIG. **29** is a partial cross-section through a cathode assembly according to another embodiment disclosed herein;

[0056] FIG. **30** is a close-up of area A of FIG. **29**;

[0057] FIG. **31** is a perspective view showing an end of a cathode block according to another embodiment disclosed herein;

[0058] FIG. **32** is a longitudinal cross-section through a cathode assembly according to another embodiment disclosed herein;

[0059] FIG. **33** shows the cathode assembly of FIG. **32**, along with possible locations of slot anchors;

[0060] FIG. **34** is an isolated view of a magnetic mounted cooling fin according to an embodiment disclosed herein; and

[0061] FIG. **35** is an isolated view of a magnetic mounted blanket according to an embodiment disclosed herein.

DETAILED DESCRIPTION OF EMBODIMENTS

[0062] 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.

[0063] 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.

[0064] FIG. **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 FIG. **1**, and a plurality of cathode assemblies **14**, of which one is shown in FIG. **1**.

[0065] 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 FIG. **1**, the surfaces **22**, **30** face one another and face the interior **16** of the reduction cell **10**.

[0066] 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**. The cell **10** further comprises an outer metal shell **11** (referred to herein as the "potshell") which encloses the refractories **34**, **36**.

[0067] 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.

[0068] 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**.

[0069] 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 FIG. **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.

[0070] 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**.

[0071] 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 FIG. **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**.

[0072] As shown most clearly in the isolated views of FIGS. **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 slot **56** shown in FIGS. **15** and **16** is of constant shape and cross-sectional area along its length. However, in other embodiments, the slot **56** may be interrupted or may vary in cross-sectional area along its length.

[0073] 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**. In the illustrated embodiment, the layer **57** of cast iron or carbon paste is provided over the top surface **55** and the two side surfaces **59** of collector bar **52** which are received within slot **56**, with the bottom surface being free of layer **57**. In another embodiment, the layer **57** of cast iron or carbon paste may also be provided over the bottom surface **53** of current collector bar **52**, so as to join both sides of layer **57** across the bottom surface **53** of the collector bar **52**.

[0074] 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.

[0075] FIGS. **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.

[0076] FIGS. **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 FIGS. **8**, **8*a*** 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 U.S. Pat. No. 3,398,081 to Bonfils et al.

[0077] 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**. FIGS. **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.

[0078] Upon rapidly freezing the thimble **64** in situ from molten iron, the iron undergoes solidification shrinkage. As shown in FIG. **5***a*, 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**.

[0079] Similarly, with reference to FIGS. **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**.

[0080] 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.

[0081] 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.

[0082] 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.

[0083] 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.

[0084] 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.

[0085] 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.

[0086] 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**.

[0087] 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.

[0088] 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**.

[0089] 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**

[0090] 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**.

[0091] In the embodiments shown in FIGS. **8**, **8***a*, **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.

[0092] FIG. **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 FIG. **8***a*, 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**.

[0093] 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 FIG. **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 FIG. **8***a*, which shows one of the impact driven, nail style thimble anchors **76** of FIG. **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 FIG. **8***a*, 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** received inside borehole **68** proximate to the second end **72** thereof. It can be seen from FIG. **8***a* 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.

[0094] 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 FIG. **10**.

[0095] 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**.

[0096] 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**.

[0097] 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 FIG. **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.

[0098] In another aspect, also shown in FIG. **9***a*, 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 FIG. **9***a*, 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.

[0099] 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**.

[0100] Although FIGS. **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, FIGS. **14***a* to **14***c* show three forms of inserts, labelled **76***a*, **76***b* and **76***c*. Insert **76***a* is in the form of a nail having a pointed tip, smooth shank and circular, enlarged head, similar to that shown in FIGS. **8** to **10**. Insert **76***b* is in the form of a lag screw or lag bolt, having a hexagonal head, a pointed tip and a threaded shank. FIGS. **14***a* and **14***b* each shows insert **76***a* or **76***b* optionally being inserted into a pre-drilled bore **68** which is smaller in diameter than the shank of the insert **76***a* or **76***b*, the bore **68** being deformed radially outwardly by the insertion of insert **76***a* or **76***b*. However, it will be understood that the bores **68** are not always necessary, depending at least partly on the diameter of the insert **76***a* or **76***b*.

[0101] Insert **76***c* shown in FIG. **14***c* is in the form of an expansion anchor having an inner threaded screw portion and an outer split sleeve portion. The insert **76***c* 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 **76***c*, causing radially outward deformation of the bore **68**.

[0102] 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.

[0103] In another embodiment now described with reference to FIGS. **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**.

[0104] The embodiment shown in FIGS. **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.

[0105] 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.

[0106] 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 FIGS. **14***d* and **14***e*, respectively.

[0107] 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.

[0108] 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 FIGS. **6** and **7**, the first ends **90** of bypass members **88** are connected to the conductor rod **38** by mechanical fastening means **83***a* and **83***b*, including nuts and bolts, each pass through or adjacent to the conductor rod **38**.

[0109] Although FIGS. **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**.

[0110] 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**.

[0111] FIGS. **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**.

[0112] 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 FIGS. **6** and **7** and **14***a* to **14***e*, 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.

[0113] In the embodiment of FIGS. **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**.

[0114] 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.

[0115] 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.

[0116] 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 FIGS. **15** and **16**, the current collector bar **52** has a flat bottom surface **53** which is substantially co-planar with the bottom surface **54** of the cathode block **20**, a top surface **55** which is opposed to the bottom surface **53**, a pair of side surfaces **59** extending between the top and bottom surfaces **55**, **53**, and a pair of end surfaces **61**.

[0117] In accordance with an embodiments shown in FIGS. **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 FIG. **17** are connected to the bottom surface **53** of each collector bar **52** by a fusion connection, whereas FIG. **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** (FIG. **19**) or clearance cavities into the bottom surface **54** of the cathode block **20** to provide the necessary clearance.

[0118] Although the strap connectors **112** are shown in FIG. **17** as extending across both sides of the slot **58**, this is not necessarily the case. Rather, as shown in FIG. **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, FIG. **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**.

[0119] Alternately, as shown in FIG. **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**.

[0120] 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 FIG. **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**.

[0121] 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 FIG. **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.

[0122] 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 FIGS. **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.

[0123] 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 FIG. **19** are shown as comprising two layers **117**.

[0124] According to another embodiment, illustrated in FIG. **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**.

[0125] 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**.

[0126] 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.

[0127] 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 FIG. **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**.

[0128] 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.

[0129] 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.

[0130] 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 coating (for example by cladding or electroplating) the mating surface **140** of the buss **46** (FIG. **11**) and/or the mating surface **142** of rod **38** (FIG. **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.

[0131] 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 FIG. **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** may be coated (for example clad or electroplated) with electrically conductive corrosion resistant material, such as any of the electrically conductive corrosion resistant metals mentioned above.

[0132] FIG. **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 the top, bottom and side surfaces **55**, **53** and **59** of the bar **52**. The cladding **141** may instead be applied only to the mating surfaces which are in contact with the cast iron layer **57** or the cathode buss **24**. Alternatively, the current collector bar **52** may be provided with a coating of the electrically conductive corrosion resistant metal, for example by electroplating. The coating or cladding may have a thickness in a range from approximately 0.05 to 10 mm.

[0133] The current collector bars **52** are typically comprised of an electrically conductive metal such as steel, which has a melting point which is substantially higher than the maximum operating temperature of the reduction cell. However, typical steel collector bars have higher electrical resistance than the electrical resistance of the aluminum metal pad, and therefore the current entering from the bath into the metal pad will preferentially conduct itself horizontally through the metal pad toward the sidewall of the cell before conducting downward through the cathode assembly **14** to the external busbar connection.

[0134] To reduce electrical resistance within the cathode assembly and horizontal electrical currents in the metal pad, an embodiment of a cathode assembly **14** shown in FIG. **29** provides includes a current collector bar **52** having a core **170** comprised of a metal with a lower electrical resistance than steel, and an outer casing **172** surrounding core **170**, the casing being comprised of a metal having a melting point substantially higher than the highest operating temperature of the reduction cell. For example, the core **170** may comprise copper or an alloy thereof, and the casing **172** may comprise steel, nickel or alloys such as stainless steel. The core **170** provides the current collector bar **52** with reduced electrical resistance, while the metal casing reduces potential corrosion of the outer surface of collector bar **52**. Furthermore, the melting point and the thickness of the casing **172** are sufficient to contain the metal of the core **170** should it temporarily melt during operation in which there is excessive heat generation. Where the core **170** may melt during operation, it will be appreciated that the casing **172** will comprise a sealed enclosure which surrounds the core **170** on all sides (i.e. top surface **55**, bottom surface **53**, side surfaces **59**, and end surfaces **61**) within the potshell **11**.

[0135] The collector bar **52** of FIG. **29** may have a preformed core **170**, with the casing **172** being applied to the core **170** by any suitable means, such as by electroplating, hot dip, sputtering or as a clad layer by bonding. Alternatively, the casing **172** may comprise a preformed shell and the core **170** may be formed by casting of metal into the casing **172**. In the former case, the preformed core **170** defines the shape of the exterior surface of the collector bar **52**, while in the latter case the preformed casing **172** defines the shape of the collector bar **52**. The cross sectional shape of the collector bar **52** may be square, rectangular or round or a combination of profiles. The outer surface of the collector bar **52** may be smooth, or it may be textured to increase the contact area between the collector bar **52** and cast iron layer **57**. For example, the outer surface of the current collector bar **52** may be textured by ribs and/or grooves.

[0136] The collector bars **52** remove heat from the cell to the environment through thermal conduction through the collector bar **52** and by convective, radiation and conductive cooling of the exposed portion of the collector bar **52** situated outside of the cell. This heat loss must be taken into account when balancing the heat loss of the cell. In an embodiment illustrated in FIG. **31**, the cross sectional area of at least one end portion **174** of collector bar **52**, located outside of slot **56** and outside the cell, is altered in order to alter the thermal conductivity and electrical resistance of the collector bar **52**. As shown in FIG. **31**, the end portion **174** of collector bar **52** is reduced in cross-sectional area relative to portions of collector bar **52** which are received inside the slot **56** of cathode block **20**. The reduction of the cross sectional area of end portion **174** reduces heat loss from the cell. The collector bar **52** shown in FIG. **31** includes a core **170** and casing **172** as discussed above with reference to FIG. **29**.

[0137] The following embodiments described with reference to FIGS. **22** to **26**, **31** and **32** relate to reducing electrical resistance between the current collector bar **52**, the cast iron layer **57** and the carbon of the cathode block **20**. Some of these embodiments 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.

[0138] FIG. **24** 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.

[0139] 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 FIGS. **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**.

[0140] An alternate arrangement for permitting axial expansion movement of the cast iron layer **57** relative to the cathode block **20** is now described with reference to FIG. **30**, which is an enlarged view of the circled portion of FIG. **29**. According to this embodiment, conductive inserts **76** embedded in the side surfaces and/or the top surface of slot **56** are provided with heads which protrude into the cast iron layer **57**. The heads may become embedded therein during casting of the iron layer **57**, thereby providing a good electrical conduction path between the cathode block **20** and the cast iron layer **57**. In this embodiment, the inserts **76** are installed through formed cavities **182** in the side surface of slot **56**, wherein the cavity **182** is sealed from filling with the molten cast iron by a metal shield or washer **184** which may be attached to the shank of the insert **176**. During operation of the cell, the collector bar **52** and cast iron layer **57** may move a small distance relative to the cathode block **20** due to differential thermal expansion between the cathode block **20** and collector bar **52**, or due to deformation of the cathode block **20**. The shank of the metal insert **76** may flex or bend within the cavity **182**, and/or the shank may partially pull out of the cathode block **20**, while maintaining good electrical conduction between the cast iron layer **57** and the cathode block **20** due to the embedded heads of inserts **76**.

[0141] As shown in FIG. **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 FIG. **22**. As shown in FIG. **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**.

[0142] Instead of using a liner, the current distribution may be enhanced by providing more inserts **76** or, as shown in FIG. **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 FIG. **25**, which will be discussed below.

[0143] 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 FIG. **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 FIG. **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**.

[0144] 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 FIG. **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**.

[0145] FIG. **26** illustrates a cathode assembly **14** according to a variant of the embodiment shown in FIG. **25**. The cathode assembly of FIG. **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**.

[0146] 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 FIG. **26**.

[0147] FIGS. **32** and **33** illustrate embodiments of a cathode assembly **14** in which the current distribution is improved by providing a lower and more uniform electrical resistance across the top surface **30** of cathode block **20** as compared to a traditional cathode assembly as seen in FIGS. **15-16**. This will reduce power consumption, reduce uneven erosion of the cathode block **20**, and reduce horizontal electrical currents in the metal pad. According to this embodiment the electrical resistance of the cathode assembly is reduced by use of the copper collector bar **170**. According to this embodiment, the electrical resistance across the top surface **30** of cathode block **20** is made more uniform by varying the distance from the top edge of cast iron layer **57** to the top surface **55** of the collector bar **52**, and to the top surface of the slot **56** of cathode block **20**, along the length of slot **56**.

[0148] As shown in FIG. **32**, the collector bar **52** is bonded to the cathode block **20** by means of cast iron layers **57** on the two lateral opposing side surfaces **59** of the collector bar **52** that reside within the cathode slot **56**. In contrast to the embodiment shown in FIGS. **15** and **16**, no cast iron layer **57** is provided between the top surface **55** of the collector bar **52**

and the top surface of the slot **56**. This space may be optionally filled with an electrically and thermally insulating refractory material **178**.

[0149] In addition, the cast iron layer **57** along each side surface **59** of collector bar **52** varies in height along the length of the collector bar **52**, being higher in the middle portion of collector bar **52** and slot **56**, and lower proximate to the ends of collector bar **52** and slot **56**. Accordingly, each cast iron layer **57** has a top edge **180** which varies in distance from the top surface **55** of collector bar **52** along the length of slot **56**, where any spaces caused by the profiling of the top edge **180** may be filled with insulating refractory material **178**. In the illustrated embodiment, the top edge **180** of cast iron layer **57** is shaped in an approximate arc profile, however, the shape can be varied from that which is shown, such as straight or polygonal profiles. Also, in this embodiment, the top edge **180** of cast iron layer **57** is substantially level with the top surface **55** of collector bar **52** at the midpoint of cathode block **20**.

[0150] With the profiled top edge **180** of cast iron layers **57**, the resistance of the cathode carbon between the top surface **30** of the cathode block **20** and the contacting surface of the iron layers **57** presents a changing electrical resistance along the length of the cathode block **20** that is offset by the changing electrical resistance along the length of the collector bar **52**, thereby presenting a near uniform electrical resistance from anywhere along the length of the top surface **30** of the cathode block **20** to the external end of the collector bar **52**. The current distribution across the width of the top surface **30** of the cathode block **20** may be made more uniform by the altering the dimensions of the slot **56** and the iron connection surface between the cathode block **20** and collector bar **52**. The shape profiles of the top edges **180** of the iron layers **57**, and the distance from the top edge **180** of the iron layers **57** to the top surface **55** of the collector bar **52**, may also be varied in adjacent cathode assemblies **14** so as to balance the current distribution across the width of the reduction cell **10**. Cast iron may be substituted equally with carbon paste used to connect the cathode block and the collector bar.

[0151] The insulating refractory material **178** between the cathode block **20** and the collector bar **52** serves to reduce the rate of heat transfer from the cathode block **20** to the collector bar **52**. This material **178** may be castable, using a temporary form, or may be preformed and positioned into the cathode slot **56** prior to positioning of the collector bar **52** and casting of the iron layer **57**.

[0152] As shown in FIG. **33**, inserts **76** such as those shown in FIG. **30** may be provided along the length of the collector bar **52**.

[0153] FIGS. **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.

[0154] In the embodiment of FIGS. **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 FIG. **29**. In the illustrated embodiment, the tongue portion **162** has an attachment flange **166** which is secured to the top surface **55** 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**.

[0155] 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.

[0156] 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**.

[0157] The thermal balance of the cell must be maintained throughout the life of the cell, so as to maintain the bath at about 25-50 degrees Celsius above its freezing temperature, while enabling the bath to freeze against the sidewall for corrosion protection of the sidewall refractory, and to prevent excessive freezing of the bath on the anode and cathode surfaces. However, the thermal conductivity of the cell changes over time due to corrosion wear of the sidewall and the cathode blocks **20**, and the energy (watts) input to the cell may change with the cell's electrical resistance. According to the embodiments shown in FIGS. **34** and **35**, the outer surface of potshell **11** (shown in FIG. **1**) may be provided with removable means for preventing the potshell **11** from becoming too hot or too cold throughout the operational life of the cell **10**.

[0158] In accordance with the embodiment of FIG. **34**, the thermal conductivity through the potshell **11** can be increased in selected locations by use of cooling fins **186** attached to the outside of the potshell **11**, with or without forced cooling. Cooling fins **186** absorb heat from the potshell **11** and cool the potshell **11** by convection of heat to the air and/or heat radiation to the environment. The increase in cooling rate provided by fins **186** will reduce the temperature of the refractory lining **34**, **36** (shown in FIG. **1**) on the inside of the potshell **11**, thereby influencing the thickness of the frozen bath layer.

[0159] Each cooling fin **186** may comprise an extruded aluminum shape with a bottom plate **188** that includes a bottom surface **190** and a top surface **192**, where the bottom surface **190** contacts the potshell **11**. Extending from the top surface **192** are one or more fins **194**. The cooling fins **186** may be comprised of aluminum, and may include a surface treatment of anodization, such as a coloured anodization, which increases the emissivity of the cooling fin material in order to increase its ability to radiate heat to the environment compared to a non-anodized aluminum cooling fin.

[0160] The cooling fins **186** may be magnetically held against the potshell **11** by one or more rare earth and/or non-ferrous magnets **196** having a curie point of at least about five hundred degrees Celsius. For example, the magnets **196** may comprise Samarium-Cobalt or Aluminum-Nickel-Cobalt (Alnico) alloyed magnets. Such magnets **196** maintain their magnetic force at high temperatures, and hold the cooling fin **186** against the side of the steel potshell **11** when it has heated beyond normal design parameters due to the wear of the internal refractory lining.

[0161] The magnets **196** are retained in the bottom plate **188**. For example, the bottom surface **190** of the bottom plate **188** may be provided with one or more cavities **198** for retaining magnets **196**, and the magnets **196** may be retained therein by retaining screws **200** or other mechanical means, and/or by bonding. The bottom plate **188** may have a groove **202** along an edge of the bottom surface **190** of plate **188** to enable prying the cooling fin **186** off of the potshell **11** for removal.

[0162] The cooling fins **186** may further comprise a thin thermal break **204** between the magnets **196** and the steel potshell **11**, through which the heat transfer into the magnets **196** will be reduced but the magnetic force will be maintained. The thermal break **204** may be attached to the external surfaces **197** of magnets **196**, and may comprise a non flammable material with low thermal conductivity. The thermal break **204** improves the performance of the magnets **196** by keeping them at a cooler temperature than without the thermal break **204**. For clarity, the thermal break **204** is shown as being removed from the external surface of the lower magnet **196** in FIG. **34**.

[0163] In accordance with the embodiment of FIG. **35**, the thermal conductivity through the potshell **11** can be decreased in selected locations by the use of external insulation on the potshell **11**, which insulation reduces the convective and radiation cooling of the potshell **11**. Due to the wear (thinning) of the internal refractory in the cell over its operational life the potshell **11** may change from being too cold to being too hot, so it is desirable to have insulation that can easily be removed if the local potshell temperature exceeds a certain level.

[0164] According to the present embodiment, the temporary thermal insulation is applied to the exterior of the potshell **11** in the form of one or more magnetically mounted blankets **206**, one of which is shown in FIG. **35**. The blanket **206** is comprised of a non-flammable, high temperature resistant material **210** having a melting point of at least about 600 degrees Celsius, such as one or more layers of a woven or unwoven, flexible glass or ceramic fibre cloth. Filler material may optionally be quilted between layers of the cloth. The blankets **206** reduce the cooling rate of the potshell **11** to the environment, thereby increasing the internal temperature of the potshell **11** adjacent to the blanket location. Blankets **206** may be overlapped and/or layered so as to cover adjacent areas and/or to enhance reduction of the cooling rate in specified regions of the potshell **11**. The flexibility of blankets **206** allows them to be positioned over structural elements of the potshell **11**.

[0165] A plurality of magnets **208** are attached to or captured within the construct of the blanket **206**, in adequate location and quantity to hold the blanket **206** against the potshell **11** and thereby reduce the convective and radiation cooling of the potshell **11** to the environment. The magnets **208** may be ferrous, nonferrous or may be comprised of a rare earth alloy. The magnets **208** may be selected by strength and curie point to lose holding power in the event that the temperature of the potshell **11**, or a portion thereof, reaches an unacceptably high level. Also, the magnets **208** are of low enough magnetic force to enable manual removal of the blankets **206** from the potshell **11**.

[0166] 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.

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; 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.

2. The electrode assembly of claim **1**, wherein:

the electrode is a pre-baked carbon anode,

the first surface of the carbon electrode block is a bottom surface thereof,

the electrically conductive metal member comprises a vertical conductor rod,

the electrically conductive metal member further comprises a vertical stub at its first end, and

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.

3. (canceled)

4. The electrode assembly of claim **2**, 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; or

wherein the insert extends into the side surface of the recess and extends radially outwardly therefrom; and/or

wherein the insert is inclined downwardly and outwardly from said second surface.

6-7. (canceled)

8. The electrode assembly of claim **4**, 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; and

wherein a portion of each of said inserts protrudes from the bottom surface or the side surface of the recess.

9-10. (canceled)

11. The electrode assembly of claim **4**, 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.

14-24. (canceled)

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 a first portion 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 layer of cast iron or carbon paste is provided in the slot, between the current collector bar and the carbon electrode block; and

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.

27. (canceled)

28. The electrode assembly of claim **26**, wherein the insert is partly received in the inner surface of the slot, and has a head which is embedded in the layer of cast iron or carbon paste.

29. The electrode assembly of claim **28**, wherein the head of the insert is flat, the electrode assembly 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.

30-41. (canceled)

42. The electrode assembly of claim **1**, 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.

43-45. (canceled)

46. The electrode assembly of claim **1**, 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. (canceled)

48. The electrode assembly of claim **1**, 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.

49-50. (canceled)

51. The electrode assembly of claim **25**, wherein the current collector bar comprises a core and an outer casing surrounding the core.

52. The electrode assembly of claim **51**, wherein the core is comprised of a first metal with a lower electrical resistance than steel, and wherein the casing is comprised of a second metal having a melting point higher than the highest operating temperature of the reduction cell.

53. The electrode assembly of claim **52**, wherein the core comprises copper or an alloy thereof.

54. The electrode assembly of claim **52**, wherein the casing comprises steel, nickel or alloys such as stainless steel.

55. The electrode assembly of claim **51**, wherein the casing comprises a sealed enclosure which surrounds the core on all sides within the potshell.

56. The electrode assembly of claim **55**, wherein the casing comprises a pre-formed shell and the core is formed by casting of the first metal into the casing.

57. (canceled)

58. The electrode assembly of claim **25**, wherein the current collector bar has a second portion extending outwardly of said slot, wherein the second portion of the collector bar comprises an end portion having a smaller cross-sectional area than the first portion of the collector bar which is received inside the slot.

59-61. (canceled)

62. The electrode assembly of claim **26**, wherein the slot has a top surface and a pair of side surfaces, and wherein the layer of cast iron or carbon paste is provided only between the side surfaces of the slot and opposing side surfaces of the current collector bar; and

wherein a space between the top surface of slot and an opposing top surface of the current collector bar is filled with an electrically and thermally insulating refractory material.

63. (canceled)

64. The electrode assembly of claim **62**, wherein the top edge of the cast iron layer between each of the side surfaces of the slot and the opposing side surface of the current collector bar varies in height along the length of the slot; and

wherein the cast iron layer has a top edge which is spaced from the top surface of the slot by a distance which varies along the length of the slot.

65-66. (canceled)

67. The electrode assembly of claim **64**, wherein said thermally insulating refractory material fills any spaces between the top edge of the cast iron layer and the top surface of the slot.

68-75. (canceled)

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