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(54) **Titre : PROCEDE D'ASSEMBLAGE DE MATERIAUX DIFFERENTS**
(54) **Title: METHOD OF JOINING DISSIMILAR MATERIALS**

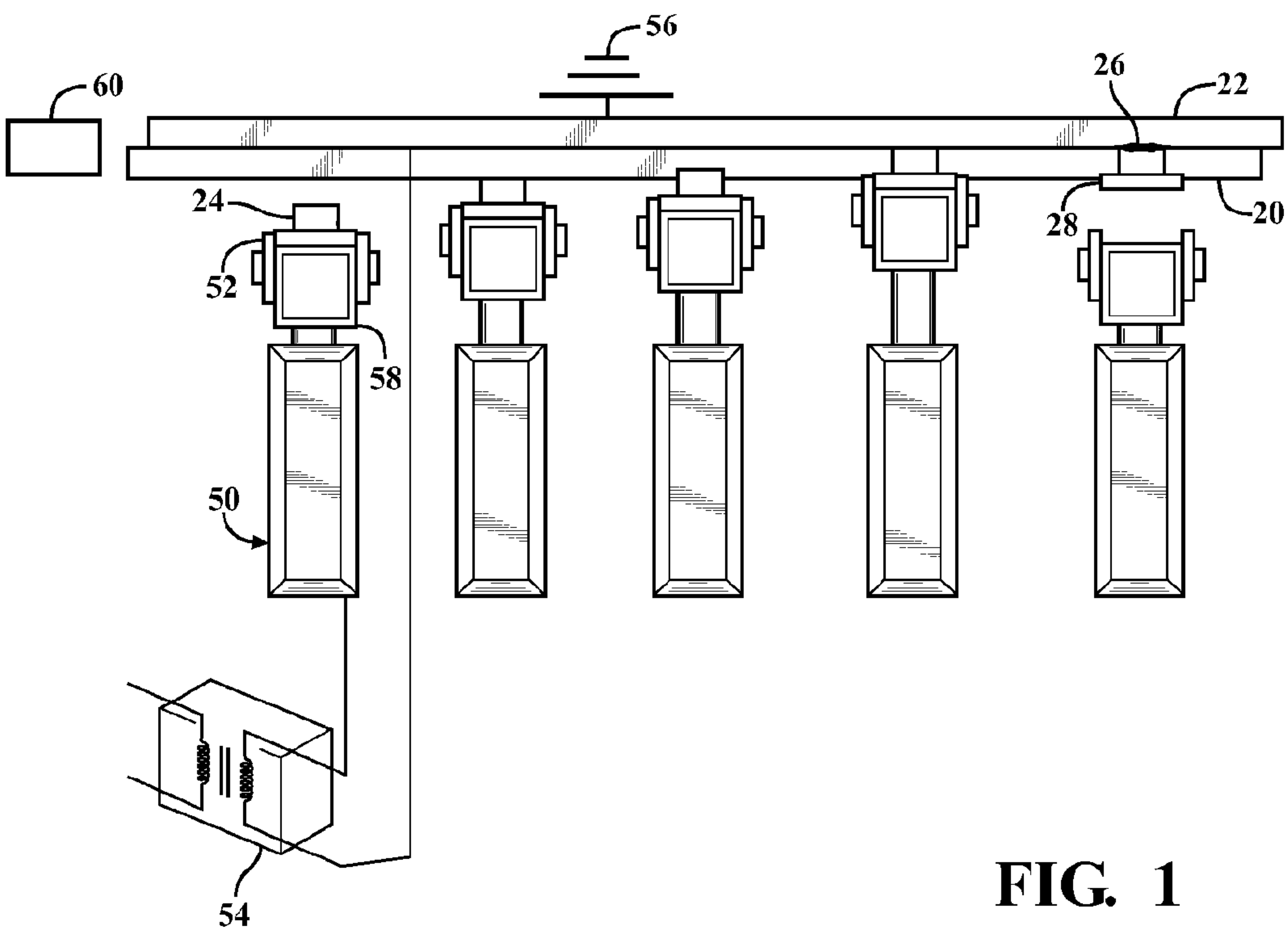

FIG. 1

(57) **Abrégé/Abstract:**
The invention provides a method of joining dissimilar materials, such as aluminum to steel, by applying low pressure and heat to minimize distortion of the materials and the heat affected zone. The method includes applying current to a weld element, at least

(57) **Abrégé(suite)/Abstract(continued):**
partially melting a portion of the first material with the heated weld element, and passing through the at least partially melted portion of the first material with the weld element. The method further includes contacting the second material with the heated weld element, and melting a portion of the weld element and a portion of the second material in contact with one another to form a weld. The weld element is designed with a head to trap the first material between the head and the second material, and a vent for receiving the at least partially melted first material as the weld element passes through.

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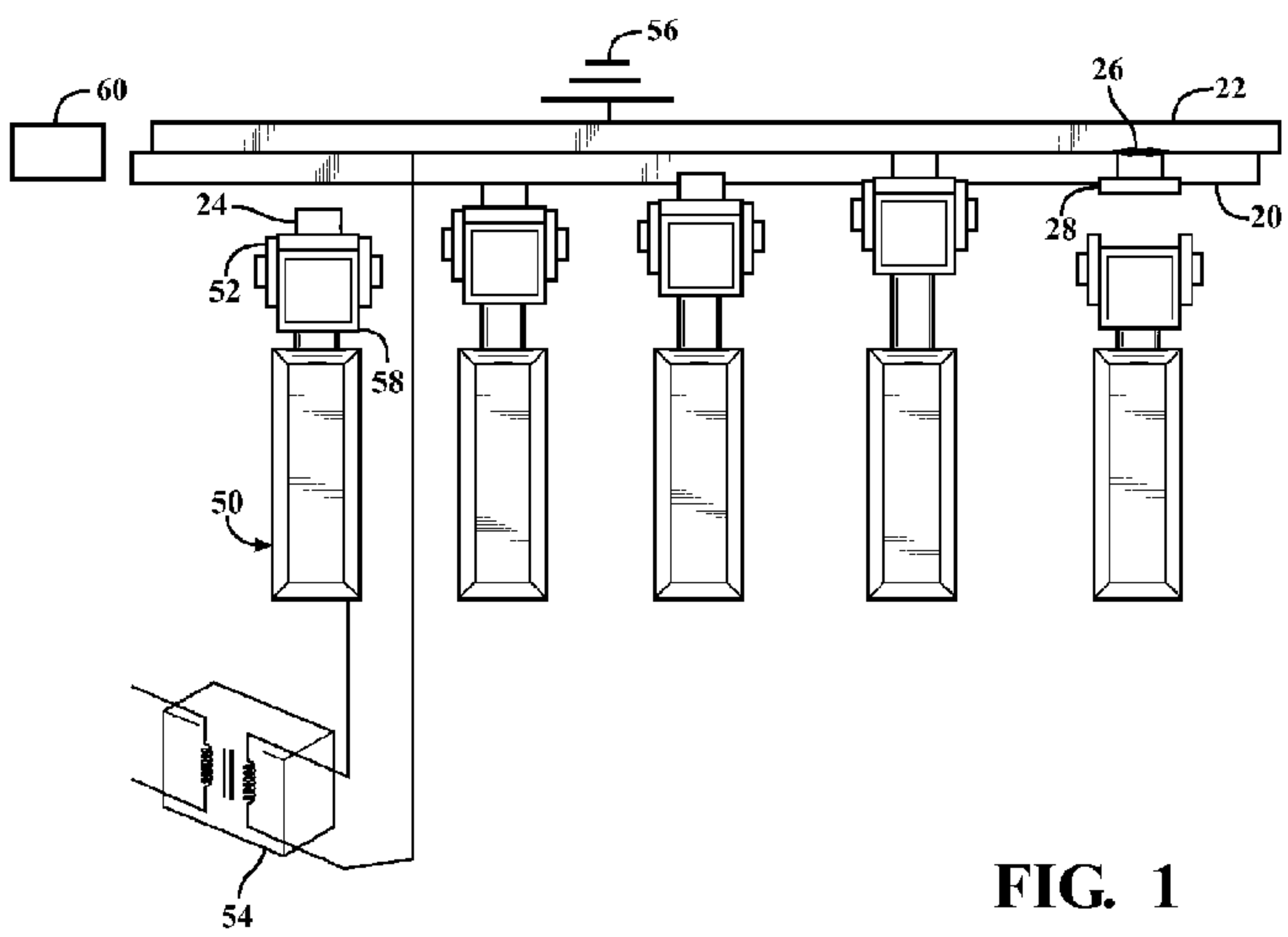

FIG. 1

(57) Abstract: The invention provides a method of joining dissimilar materials, such as aluminum to steel, by applying low pressure and heat to minimize distortion of the materials and the heat affected zone. The method includes applying current to a weld element, at least partially melting a portion of the first material with the heated weld element, and passing through the at least partially melted portion of the first material with the weld element. The method further includes contacting the second material with the heated weld element, and melting a portion of the weld element and a portion of the second material in contact with one another to form a weld. The weld element is designed with a head to trap the first material between the head and the second material, and a vent for receiving the at least partially melted first material as the weld element passes through.

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METHOD OF JOINING DISSIMILAR MATERIALS

CROSS-REFERENCE TO PRIOR APPLICATIONS

[0001] This PCT Patent Application claims the benefit of U.S. Provisional Patent Application Serial No. 61/938,367 filed February 11, 2014, entitled "Method Of Joining Dissimilar Materials," the entire disclosure of the application being considered part of the disclosure of this application and hereby incorporated by reference.

BACKGROUND OF THE INVENTION

1. Technical Field

[0001] The invention relates generally to a method of joining dissimilar materials, a system for joining the dissimilar materials, and a structure including the joined dissimilar materials.

2. Related Art

[0002] Structural components for automotive vehicles, such as beams, pillars, and rails, oftentimes comprise dissimilar materials, for example a first material having a higher strength and a second material having a higher ductility. Various methods can be used to join the dissimilar materials together, for example welding or riveting. One welding technique used to join dissimilar materials is insert welding. This technique includes forcing a rivet through the first material and welding the rivet to the second material.

[0003] However, the known methods for joining dissimilar materials have drawbacks related to process time, reliability, quality, and/or costs. For example, welding becomes a challenge when the materials have significantly different melting points and thermal expansion coefficients, such as aluminum and steel. Insert welding also requires high loads, which means expensive equipment and possibly significant damage to the materials being joined. Also, many welding techniques require access to opposing sides of the materials to be joined, which is not possible in some cases.

SUMMARY OF THE INVENTION

[0004] The invention provides a method of joining dissimilar materials using a weld element with reduced pressure and heat, and thus minimal distortion of the materials and reduced costs. The method includes disposing a first material along a second material, the first and second materials being dissimilar. The method further includes disposing a weld element along the first material, wherein the weld element includes a vent extending from a first end to a second end, and applying current to the weld element to heat the weld element. The method then includes at least partially melting a portion of the first material and passing through the at least partially melted portion of the first material with the heated weld element. The at least partially melted portion of the first material can enter the second end of the vent and flow toward the first end of the vent as the heated weld element passes through the first material. After passing through the at least partially melted portion of the first material, the method includes contacting the second material with the heated weld element, and melting a portion of the weld element and a portion of the second material in contact with one another to form a weld.

[0005] The invention also provides a system for joining the dissimilar materials. The system includes the first material disposed along the second material, and the weld element including the vent disposed along the first material. An energy source is connected to a primary electrode, and the energy source applies current to the primary electrode while the primary electrode engages the weld element. The heated weld element at least partially melts a portion of the first material, passes through the at least partially melted portion of the first material, and contacts the second material. A portion of the weld element and a portion of the second material in contact with one another melt to form the weld.

[0006] The invention further provides a structure including the dissimilar materials joined together with the weld element. The first material is disposed along the second material, and the weld element extends through the first material. The weld element extends along a center axis from a first end to a second end, and the second end is welded to the second material. The weld element also includes a vent extending along the center axis from the first end to the second end, and the vent may contain a re-solidified portion of the first material.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] Figure 1 illustrates five phases of an exemplary method for joining dissimilar materials with a weld element;

[0008] Figure 1A is a side cross-sectional view of the dissimilar materials and the weld element during the second-fourth phases shown in Figure 1;

[0009] Figure 2 is a side cross-sectional view of another embodiment wherein more than two dissimilar materials are joined using the weld element;

[0010] Figure 3 is a top view of the weld element according to an exemplary embodiment, wherein an outer surface of the weld element presents a circular shape and a head of the weld element is keyed;

[0011] Figure 4 is a top view of the weld element according to another embodiment, wherein the outer surface presents a hexagonal shape;

[0012] Figure 5 is a top view of the weld element according to yet another embodiment, wherein the outer surface presents a rectangular shape;

[0013] Figure 6 is a side cross-sectional view of the weld element according to another embodiment with a chamfered first end and a vent width decreasing from the first end to the second end;

[0014] Figure 7 is a side cross-sectional view of the weld element according to yet another embodiment with a sharp first end and a vent width decreasing from the first end to the second end;

[0015] Figure 8 is a side cross-sectional view of the dissimilar materials and the weld element according to an another embodiment, wherein the weld element is disposed at an edge of the first material;

[0016] Figure 8A is a top view of the dissimilar materials and the weld element of Figure 8; and

[0017] Figure 9 is a side cross-sectional view of the dissimilar materials and the weld element according to yet another embodiment, wherein the head of the weld element is pressed into the first material.

DESCRIPTION OF ENABLING EMBODIMENTS

[0018] The invention provides an improved method of joining dissimilar first and second materials **20, 22**, such as aluminum to steel, with low pressure and heat, and thus low costs and minimal distortion of the materials **20, 22**. The method includes at least partially melting through the first material **20** and contacting the second material **22** with a heated weld element **24**. A connection **28** is formed between the weld element **24** and the first material **20**, and a metallurgical bond, i.e. weld **26**, is formed between the weld element **24** and the second material **22**. Preferably, the geometry of the weld element **24** is designed to trap the first material **20** between the weld element **24** and the second material **22**, i.e. to create an in-situ mechanical bond, once the weld **26** is in place.

[0019] An exemplary embodiment of the method is generally illustrated in Figure 1. The method first includes providing the first material **20** and the second material **22**. Typically, both of the materials **20, 22** are provided in the form of a tube or sheet. The materials **20, 22** could also be castings of various different shapes. The size and dimensions of the materials **20, 22** can vary depending on the intended application of the product. In the exemplary embodiment, both materials **20, 22** are provided in the form of a sheet having a thickness $\mathbf{t_1}$, $\mathbf{t_2}$ of not greater than 2 millimeters. However, there is no limit to the thickness $\mathbf{t_1}$, $\mathbf{t_2}$ of the dissimilar materials **20, 22** that can be joined using the weld element **24**, as the size and dimensions of the weld element **24** can be designed accordingly. For example, if the materials **20, 22** have a large thickness $\mathbf{t_1}$, $\mathbf{t_2}$, the length of the weld element **24** can be increased.

[0020] Various different material compositions can be joined by the weld element **24**, but the first material **20** typically has a lower melting point and a lower electrical resistivity than the second material **22**. The first material **20** is a non-ferrous based metal and/or a carbon fiber composite. In the exemplary embodiments, the first material **20** is an aluminum alloy or another aluminum-based material, for example the aluminum alloy sold under the designation 5182. The second material **22** is a ferrous-based metal. In the exemplary embodiment, the second material **22** is steel, for example the type of steel sold under the name 60G60G.

[0021] Although the exemplary embodiment of Figures 1 and 1A shows the weld element **24** joining only two dissimilar materials **20, 22** the method can alternatively including joining more than two dissimilar materials. Figure 2 shows an example of four materials **20, 22, 30, 32** joined together by the weld element **24**, wherein third and fourth materials **30, 32** are disposed between the first and second materials **20, 22**. In this example, the third material **30** is formed of magnesium, and the fourth material **32** is formed of aluminum.

[0022] The method also begins by providing the weld element **24**. In the exemplary embodiment shown in Figures 1 and 1A, the weld element **24** is a rivet extending longitudinally along a center axis **A** from a first end **34** to a second end **36**. This weld element **24** includes a head **38** extending outwardly and perpendicular to the center axis **A** and a shaft **40** extending along the center axis **A** from the head **38** to the second end **36**. The weld element **24** also includes an outer surface **42** facing away from the center axis **A** and presenting an outer width $\mathbf{w_o}$ which extends perpendicular to the center axis **A**. The outer width $\mathbf{w_o}$ at the first end **34** is typically greater than the outer width $\mathbf{w_o}$ at the second end **36**. In the exemplary embodiment, the outer width $\mathbf{w_o}$ is greater along the head **38** than the shaft **40**. The outer width $\mathbf{w_o}$ is also constant along the entire head **38** from the first end **34** to the shaft **40**, and constant along the entire shaft **40** from the head **38** to the second end **36**. Alternatively, the outer width $\mathbf{w_o}$ could taper continuously between the first end **34** and the second end **36**, as shown in Figure 2. In another embodiment, the head **38** of the weld element **24** is keyed, as shown in Figure 3. The keyed feature on the head **38** can be used to conduct a non-destructive torque test and thus determine the strength of the weld element **24** joining the materials **20, 22** together. For example, a wrench can be used to engage the keyed head **38** and apply torque to the weld element **24** to measure the strength of the connection between the materials **20, 22**.

[0023] The outer surface **42** of the weld element **24** can present various different shapes when viewed in cross-section. In one embodiment, the outer surface **42** of both the head **38** and the shaft **40** present a circular shape, as shown in Figure 3. The outer surface **42** of the weld element **24** could alternatively present a hexagonal shape, as shown in Figure 4, or a rectangular shape, as shown in Figure 5. In addition, the head **38** and shaft **40** could present shapes which are different from one another.

[0024] The weld element **24** also preferably includes an inner surface **44** presenting a vent extending along the center axis **A** and continuously from the first end **34** to the second end **36**, as shown in Figures 1, 2, 6, and 7, so that while melting or partially melting through the first material **20**, the at least partially melted portion of the first material **20** can enter the vent at the second end **36** and flow toward the first end **34** of the weld element **24**. The outer surface **42** of the weld element **24** creates a cut line as it passes through the at least partially melted first material **20**, which directs the at least partially melted first material **20** through the vent. The inner surface **44** of the weld element **24** presents a vent width $\mathbf{w_v}$ extending perpendicular to the center axis **A**, which can vary depending on the desired flow of the at least partially melted first material **20**. In the embodiment shown in Figures 1 and 2, the vent width $\mathbf{w_v}$ is constant from the first end **34** to the second end **36**. In the embodiment of Figures 6 and 7, the vent width $\mathbf{w_v}$ is greater at the first end **34** than the second end **36**. In another embodiment, the inner surface **44** of the weld element **24** includes threads along the vent for attachment of another component.

[0025] In addition, the ends **34, 36** of the weld element **24** can be flat or sharp. For example, in the embodiment of Figure 1, both the first and second ends **34, 36** include a flat surface. In the embodiment of Figure 2, the first end **34** is flat and the second end **36** is sharp. In the embodiment of Figure 6, the first end **34** is chamfered to present a flat surface, and the second end **36** is also flat. In Figure 7, the first end **34** is sharp and the second end **36** is flat.

[0026] The weld element **24** can be formed of various different materials, but is typically formed of a material having a melting point and electrical resistivity greater than the first material **20** and similar to the second material **22**, for example steel or another iron-based material. In the exemplary embodiment, the weld element **24** is formed of steel sold under the name 1018 steel. In another embodiment, the weld element **24** is formed of a plurality of different materials. For example, the weld element **24** can include a layer of stainless steel disposed along the second end **36** while the remainder of the weld element **24** is formed of a ferrous-based material having a higher melting point and electrical resistance than the stainless steel. A coating can optionally be applied to the weld element **24**. In one embodiment, the weld element **24** is electro-coated with a layer of stainless steel or an aluminum-based material, for example an aluminum alloy of the 4000 series.

[0027] Once the materials **20, 22** and weld element **24** are obtained, the method includes disposing a contact surface **46** of the first material **20** along and parallel to a contact surface **47** of the second material **22**. The method can also include joining more than two dissimilar materials using the weld element **24**. When additional materials are joined, the additional materials **30, 32** are also disposed along the first and second materials **20, 22**, as shown in Figure 2. In the exemplary embodiment shown in Figures 1 and 1A, the method includes disposing the second material **22** above the first material **20**. This position assists in the flow of the at least partially melted first material **20** through the vent, and thus allows a lower pressure to be applied to the weld element **24**.

[0028] The method also includes disposing the second end **36** of the weld element **24** on an exposed surface **48** of the first material **20** opposite the contact surface **46** in preparation to join the materials **20, 22**. An advantage provided by the method is that it only requires access to one side of the materials **20, 22** to be joined, not both sides as in other joining methods. In the exemplary embodiment shown in Figure 1, a welding apparatus **50** with a holding device **52** places the weld element **24** on the first material **20**. The weld element **24** is typically positioned along the first material **20** so that the entire outer surface **42** of the weld element **24** is surrounded by the first material **20** after the weld element **24** melts through or at least partially melts through the first material **20**, as shown in Figures 1 and 2. However, the weld element **24** could be disposed along an edge of the first material **20**, as shown in Figures 8 and 8A.

[0029] As alluded to above, the method next includes using the weld element **24** to melt or at least partially melt a portion of the first material **20**, pass through the at least partially melted portion of the first material **20** with a low force, and form the weld **26**

between the weld element **24** and the second material **22**. This step includes applying current to the weld element **24** to heat the weld element **24** while applying a low pressure to the heated weld element **24**. In the exemplary embodiment, the welding apparatus **50** includes a primary electrode **58** contacting the weld element **24**, and an energy source **54** providing the current to the primary electrode **58** and the weld element **24**. The second material **22** provides a ground for the primary electrode **58**, which allows for one-sided access during the welding process. Alternatively, a separate ground electrode **56** may contact the second material **22** when the current is being applied.

[0030] In one embodiment, the energy source **54** is an AC transformer with a positive connection to the primary electrode **58**. The AC transformer also provides a negative connection to the second material **22**. In this example, the positive connection is approximately 480 VAC, and the negative connection is approximately 9 to 21 VAC. However, other types of energy sources **54**, such as a DC transformer, can be used.

[0031] The step of applying the current to the weld element **24** typically includes applying a low current when melting or partially melting through the first material **20** with the weld element **24**, and applying an equal or greater current once the weld element **24** contacts the second material **22** to form the weld **26** between the weld element **24** and the second material **22**. For example, in the exemplary embodiment, the method includes providing the current from the transformer to the primary electrode **58** while the primary electrode **58** engages the first end **34** of the weld element **24** for a first duration of time followed by a second duration of time, wherein the current is greater during the second duration of time. The step of passing through the at least partially melted portion of the first material **20** occurs during the first duration of time. The first duration of time ends and the second duration of time begins when the second end **36** of the weld element **24** contacts the contact surface **47** of the second material **22**. The step of forming the weld **26** between the weld element **24** and the second material **22** then occurs during the second duration of time.

[0032] A sensor **60** can be used to determine the location of the weld element **24** relative to at least one of the surfaces of the materials **20, 22** and thus determine when the second end **36** of the weld element **24** engages the contact surface **47** of the second material **22**. The welding apparatus **50** continues moving the weld element **24** longitudinally into the at least partially melted portion of the first material **20** until the weld element **24** contacts the second material **22**. Once the weld element **24** contacts the second material **22**, the welding apparatus **50** stops pressing the weld element **24**, or only presses the weld element **24** a very short distance into the melted portion of the second material **22**, to form the weld **26**. In the embodiments shown in Figure 1, 8, and 9, the head **38** of the weld element **24** traps the first material **20** between the head **38** and the second material **22**, and the weld **26** metallurgically bonds the weld element **24** to the second material **22** to secure the weld element **24** and materials **20, 22** in position. The weld **26** has a high strength and fatigue, and thus is reliable for use in various automotive application, such as beams, pillars, and rails.

[0033] As mentioned above, the current applied during the second duration of time can be equal to or greater than the current applied during the first duration of time. In the exemplary embodiment, the current during the first duration of time reaches approximately 13-15 kA, and the current during the second duration of time is greater. The current can be increased sharply at the end of the first duration of time, or increased gradually and continuously from the first to the second duration of time. In addition, the current can be constant or vary during the first and second durations of time. In the exemplary embodiment, the method includes varying the current during the first duration of time and maintaining the current constant throughout the second duration of time.

[0034] Due to the different current levels applied, the method includes heating the weld element **24** to an equal or higher temperature during the second duration of time than the first duration of time. In the exemplary embodiment, the temperature of the weld element **24** is higher during the second duration of time. When the weld element **24** is formed of an iron-based material, the maximum temperature of the weld element **24** at any point during the method should not exceed 700° C, and is preferably just above 600° C during the second duration of time to form the weld **26**.

[0035] As mentioned above, the pressure is applied to the weld element **24** while the current is applied to move the heated weld element **24** through the at least partially melted portion of the first material **20**. In the exemplary embodiment, this step includes applying a load to the primary electrode **58** while the primary electrode **58** engages and provides current to the weld element **24**. The load applied to the weld element **24** is low compared to other methods used to join materials with a rivet. This low pressure minimizes distortion and prevents significant distortion of the first and second materials **20, 22** in the portions which are not melted or partially melted. Preferably, while passing through the at least partially melted portion of the first material **20** with the low force, the heated weld element **24** does not deform adjacent portions of the first material **20** which are not melted or partially melted by the heated weld element **24**. In other words, the first and second materials **20, 22** are not forcibly penetrated, punctured, or pierced, as in other methods used to join dissimilar materials. Typically, the first and second material **20, 22** maintain the same shape throughout the welding process, except for the melted or partially melted portion of the first material **20** adjacent the weld element **24**, and the weld **26** between the second material **22** and the weld element **24**. In the exemplary embodiment, the load applied to the weld element **24** is not greater than 300 pounds and is maintained constant during the first duration of time and the second duration of time. Alternatively, the load can vary throughout either or both durations of time, but is still kept at a low value.

[0036] As discussed above, applying the current and low pressure to the heated weld element **24** melts or partially melts a portion of the first material **20** adjacent the second end **36** of the weld element **24**. The at least partially melted first material **20** can flow into the vent at the second end **36** and through the vent toward the first end **34** of the weld element **24**. However, in some cases, the first material **20** does not flow into the vent. Only a small portion of the first material **20** melts or partially melts, and the remaining portions remain solid. The at least partially melted first material **20** then solidifies around the weld element **24** and in the vent, which may prevent corrosion of the weld element **24** and materials **20, 22** disposed along the weld element **24**. Once the second end **36** of the weld element **24** contacts the second material **22**, the current is increased to melt a portion of the weld element **24** along the second end **36**, as well as a portion of the second material **22** contacted by the second end **36** of the weld element **24**. Only small portions of the weld element **24** and second material **22** melt, and the remaining portions remain solid. The melted portions solidify and form the weld **26**.

[0037] In the exemplary embodiment shown in Figure 1, the head **38** of the weld element **24** is pressed a short distance into the first material **20** and forms a connection **28** therebetween. Alternatively, the head **38** could contact and rest on the exposed surface **48** of the first material **20** to form the connection **28**. In this case, the head **38** remains outward of the first material **20**. The head **38** could alternatively be pressed past the exposed surface **48** and into the first material **20** in order to reduce corrosion along surfaces of the weld element **24**. For example, the head **38** could be countersunk in the first material **20**. In embodiments wherein the weld element **24** does not include the head **38**, the first end **34** of the weld element **24** could be flush with the exposed surface **48** of the first material **20**, remain outward of the exposed surface **48** of the first material **20**, or pressed inward of the exposed surface **48** of the first material **20** to reduce corrosion. Once the weld **26** is formed, the welding apparatus **50** retracts and the method can be repeated.

[0038] As discussed above, the method of the present invention provides many advantages, including low pressure and heat, and thus low costs and minimal distortion of the first and second materials **20, 22**, a small heat affected zone between the two materials **20, 22**, a strong weld **26**, and possibly corrosion resistance. In addition, the method only requires access to one side of the materials **20, 22** to be joined, and there is no limit to the thickness **t** of the materials **20, 22**. Another advantage of the method is a fast cycle time. The first duration of time during which the weld element **24** passes through the first material **20** is typically less than 0.5 seconds. The second duration of time during which the weld **26** is formed is also typically less than 0.5 seconds. In the exemplary embodiment, the total time from when the weld element **24** begins to at least partially melt the first material **20** and the formation of the weld **26** is not greater than 0.8 seconds.

[0039] The invention also provides a system for joining dissimilar materials **20, 22**, such as aluminum to steel, according to the method described above. An example of the system is shown in Figure 1. The system includes the first and second materials **20, 22**, the weld element **24**, the welding apparatus **50**, and the energy source **54**. The energy source **54** is connected to the primary electrode **58** of the welding apparatus **50** and applies current to the primary electrode **58** while the primary electrode **58** engages and applies low pressure to the weld element **24**. The heated weld element **24** at least partially melts a portion of the first material **20**, passes through the at least partially melted portion of the first material **20** with low force, and contacts the second material **22**. A portion of the weld element **24** and a portion of the second material **22** in contact with one another then melt to form the weld **26**. The system can also include the sensor **60** determining when the weld element **24** contacts the second material **22**, so that the energy source **54** can apply the greater current once the weld element **24** contacts the second material **22**.

[0040] The invention also provides a structure including the dissimilar materials **20, 22** joined by the weld element **24** extending through the first material **20** and welded to the second material **22**, according to the method described above. An example of the structure is shown in Figure 1. The structure includes the first material **20** disposed along the second material **22**. The first and second materials **20, 22** are dissimilar, for example, the first material **20** can be an aluminum-based material, and the second material **22** and the weld element **24** can be iron-based. The weld element **24** extends along a center axis **A** from the first end **34** to the second end **36**. The first end **34** is disposed along the first material **20** and the second end **36** is welded to the second material **22**. The weld element **24** also includes the vent extending along the center axis **A** from the first end **34** to the second end **36**, and the vent contains a re-solidified portion of the first material **20**.

[0041] Obviously, many modifications and variations of the present invention are possible in light of the above teachings and may be practiced otherwise than as specifically described while within the scope of the following claims.

CLAIMS

Claim 1. A method of joining dissimilar materials, comprising the steps of:

disposing a first material along a second material, the first and second materials being dissimilar;

disposing a weld element along the first material, the weld element including a vent extending from a first end to a second end;

applying current to the weld element to heat the weld element;

at least partially melting a portion of the first material and passing through the at least partially melted portion of the first material with the heated weld element;

contacting the second material with the heated weld element after passing through the at least partially melted portion of the first material; and

melting a portion of the weld element and a portion of the second material in contact with one another to form a weld.

Claim 2. The method of claim 1 including trapping the first material between the weld element and the second material.

Claim 3. The method of claim 1, wherein the first material is a non-ferrous based metal, and the second material and the weld element are ferrous-based metals.

Claim 4. The method of claim 1, wherein the step of applying current includes applying the current for a first duration of time followed by a second duration of time, wherein the current during the second duration of time is equal or greater than the current during first duration of time, the step of passing through the at least partially melted portion of the first material occurs during the first duration of time, the first duration of time ends when the weld element contacts the second material, and the step of forming the weld between the weld element and the second material occurs during the second duration of time.

Claim 5. The method of claim 4 including varying the current during the first duration of time and maintaining the current constant during the second duration of time.

Claim 6. The method of claim 1, wherein the step of passing through the at least partially melted portion of the first material with the heated weld element includes applying pressure to the heated weld element at a level of not greater than 300 pounds.

Claim 7. The method of claim 1, wherein the weld element includes an outer surface facing away from a center axis and presenting an outer width extending perpendicular to the center axis, and the outer width is greater at the first end than the second end.

Claim 8. The method of claim 1, wherein the weld element includes a head extending outwardly from and perpendicular a center axis, and further including the step of contacting an exposed surface of the first material with the head of the weld element.

Claim 9. The method of claim 1, wherein the weld element includes a head extending outwardly from and perpendicular to a center axis at the first end, and the head of the weld element is keyed.

Claim 10. The method of claim 1 including disposing the second material above the first material while applying the current to the weld element.

Claim 11. The method of claim 1, wherein the step of applying the current includes providing the current from a transformer to a primary electrode while the primary electrode engages the weld element, and further including applying pressure to primary electrode while the primary electrode engages and provides current to the weld element.

Claim 12. The method of claim 1, wherein the first material is aluminum-based and comprises a sheet, tube, or casting,

the second material is iron-based and comprises a sheet, tube, or casting,

the weld element is iron-based and extends longitudinally along a center axis from a first end to a second end, the weld element includes a head extending outwardly from and perpendicular to the center axis, and the weld element includes a vent extending continuously along the center axis from the first end to the second end; and further including the steps of:

disposing a contact surface of the first material along and parallel to a contact surface of the second material;

disposing the second material above the first material;

disposing the second end of the weld element on an exposed surface of the first material opposite the contact surface;

the step of applying the current including providing the current from a transformer to a primary electrode while the primary electrode engages the first end of the weld element for a first duration of time followed by a second duration of time, wherein the step of passing through the at least partially melted portion of the first material occurs during the first duration of time, the first duration of time ends when the weld element contacts the second material, and the step of forming the weld between the weld element and the second material occurs during the second duration of time, the first duration of time being less than 0.5 seconds, and the second duration of time being less than 0.5 seconds;

the step of applying the current including applying a greater current during the second duration of time than the first duration of time;

the step of applying the current including varying the current during the first duration of time and maintaining the current constant throughout the second duration of time;

the step of applying the current including heating the weld element to a higher temperature during the second duration of time than the first duration of time;

contacting the second material with a ground electrode while applying the current;

determining the location of the weld element relative to at least one of the surfaces of the first material and the second material as the weld element passes through the first material to determine when the second end of the weld element contacts the second material;

beginning the second duration of time with the greater current once the second end of the weld element contacts the second material;

applying pressure to the weld element by applying a load to the primary electrode while the primary electrode engages and provides current to the weld element;

the step of applying the pressure to the weld element including maintaining the load constant during the first duration of time and the second duration of time;

contacting the exposed surface of the first material with the head of the weld element; and trapping the first material between the head of the weld element and the second material.

Claim 13. A method of joining dissimilar materials, comprising the steps of:

disposing a first material along a second material, the first and second materials being dissimilar;

disposing a weld element along the first material, the weld element including a vent extending from a first end to a second end;

applying current to the weld element to heat the weld element;

at least partially melting a portion of the first material and passing through the at least partially melted portion of the first material with the heated weld element;

contacting the second material with the heated weld element after passing through the at least partially melted portion of the first material;

melting a portion of the weld element and a portion of the second material in contact with one another to form a weld; and

trapping the first material between the weld element and the second material to form a mechanical bond.

Claim 14. A system for joining dissimilar materials, comprising:

a first material disposed along a second material, the first and second materials being dissimilar;

a weld element disposed along the first material, the weld element including a vent extending from a first end to a second end;

an energy source connected to a primary electrode, wherein the energy source applies current to the primary electrode while the primary electrode engages the weld element, thereby heating the weld element to at least partially melt a portion of the first material, passing through the at least partially melted portion of the first material with the weld element, contacting the second material with the weld element, and melting a portion of the weld element and a portion of the second material in contact with one another to form a weld.

Claim 15. The system of claim 14 including a sensor determining when the weld element contacts the second material, and applying a greater current once the weld element contacts the second material.

Claim 16. A structure, comprising:

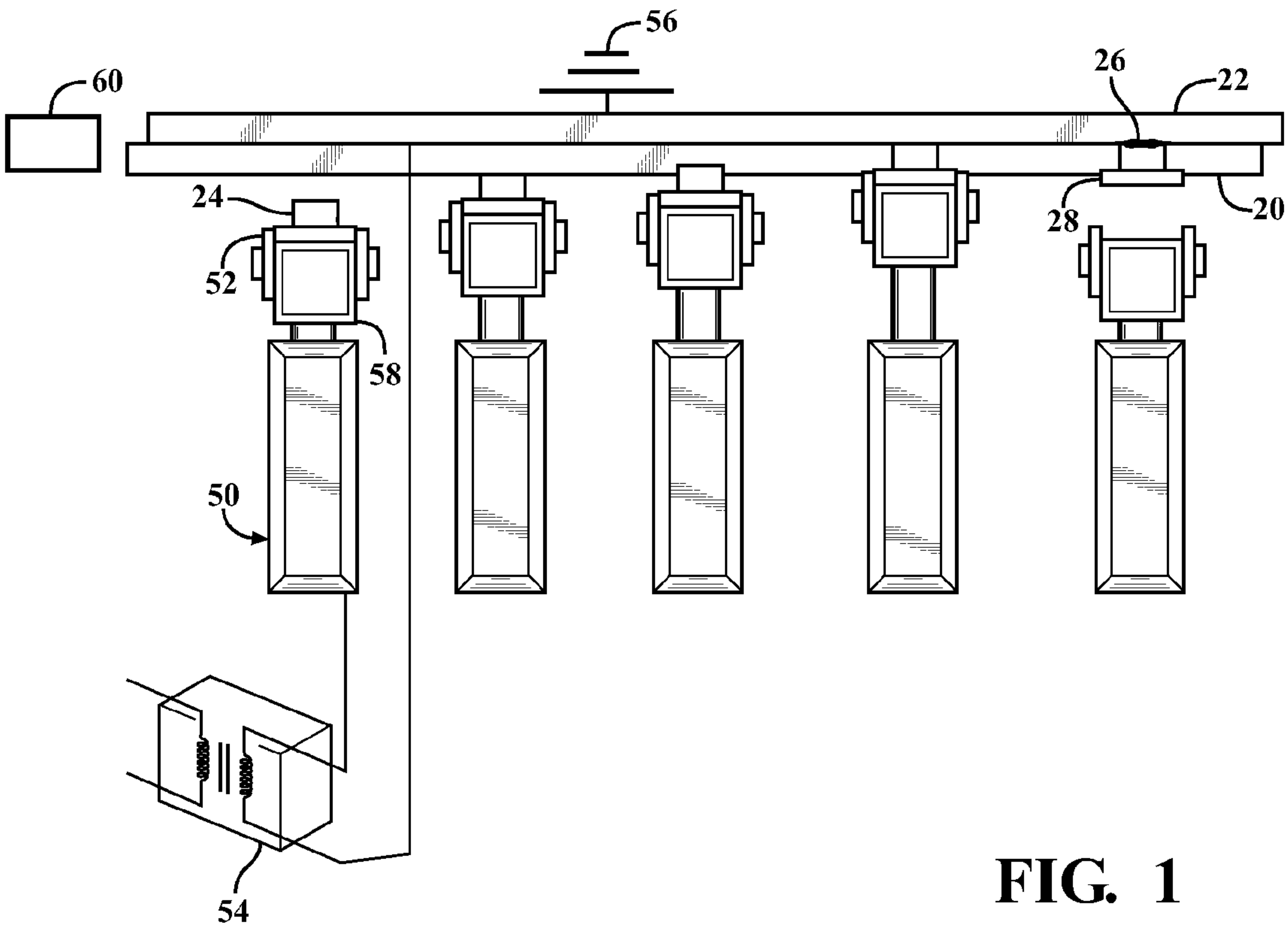
a first material disposed along a second material, the first and second materials being dissimilar;

a weld element extending through the first material, the weld element extending along a center axis from a first end to a second end, wherein the second end is welded to the second material; and

the weld element including a vent extending from the first end to the second end.

Claim 17. The structure of claim 16, wherein the first material is trapped between the weld element and the second material.

Claim 18. The structure of claim 17, wherein the weld element includes a head extending outwardly from the center axis for trapping the first material between the head of the weld element and the second material.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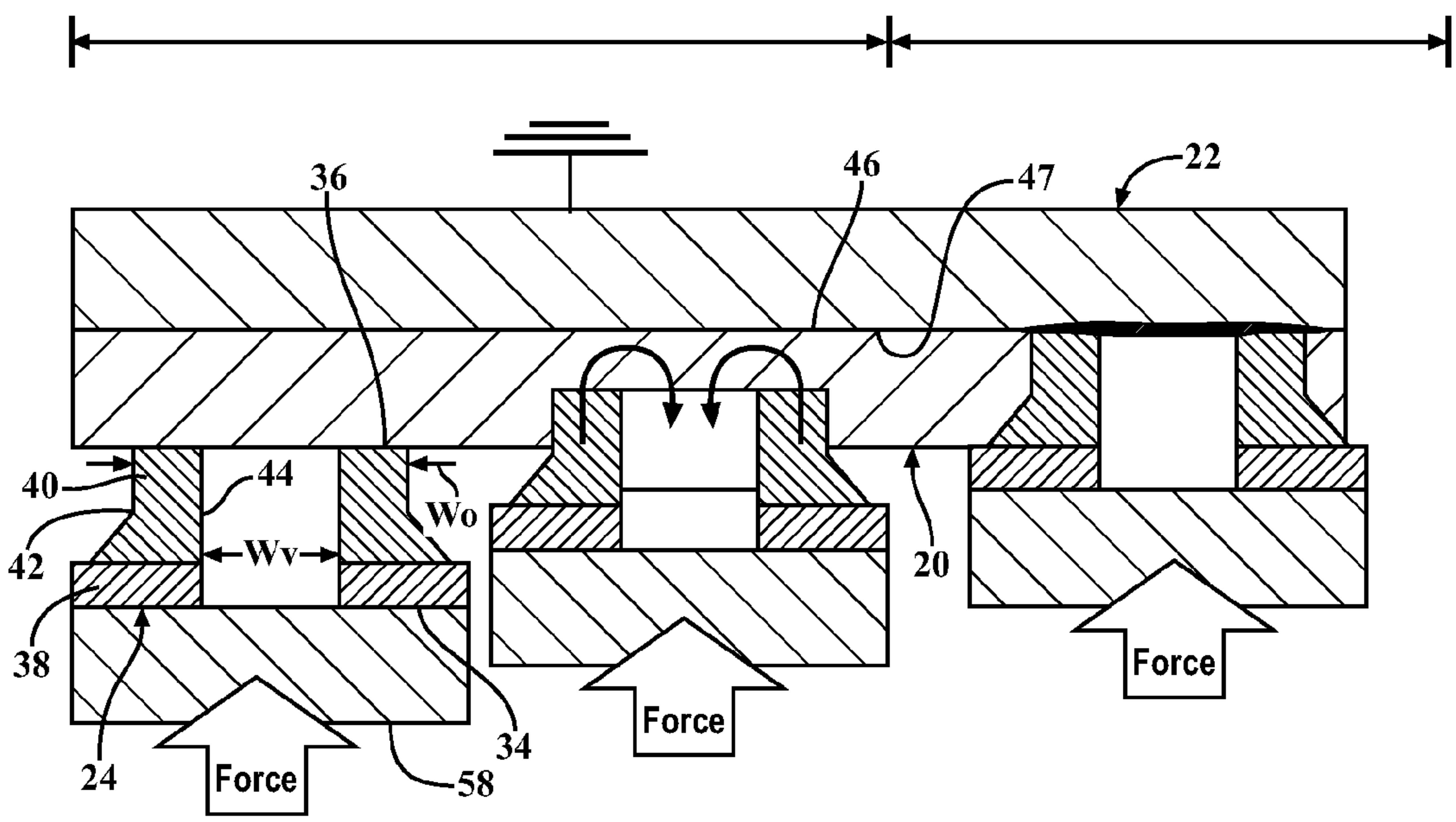
54

FIG. 1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Force

FIG. 1A

FIG. 2

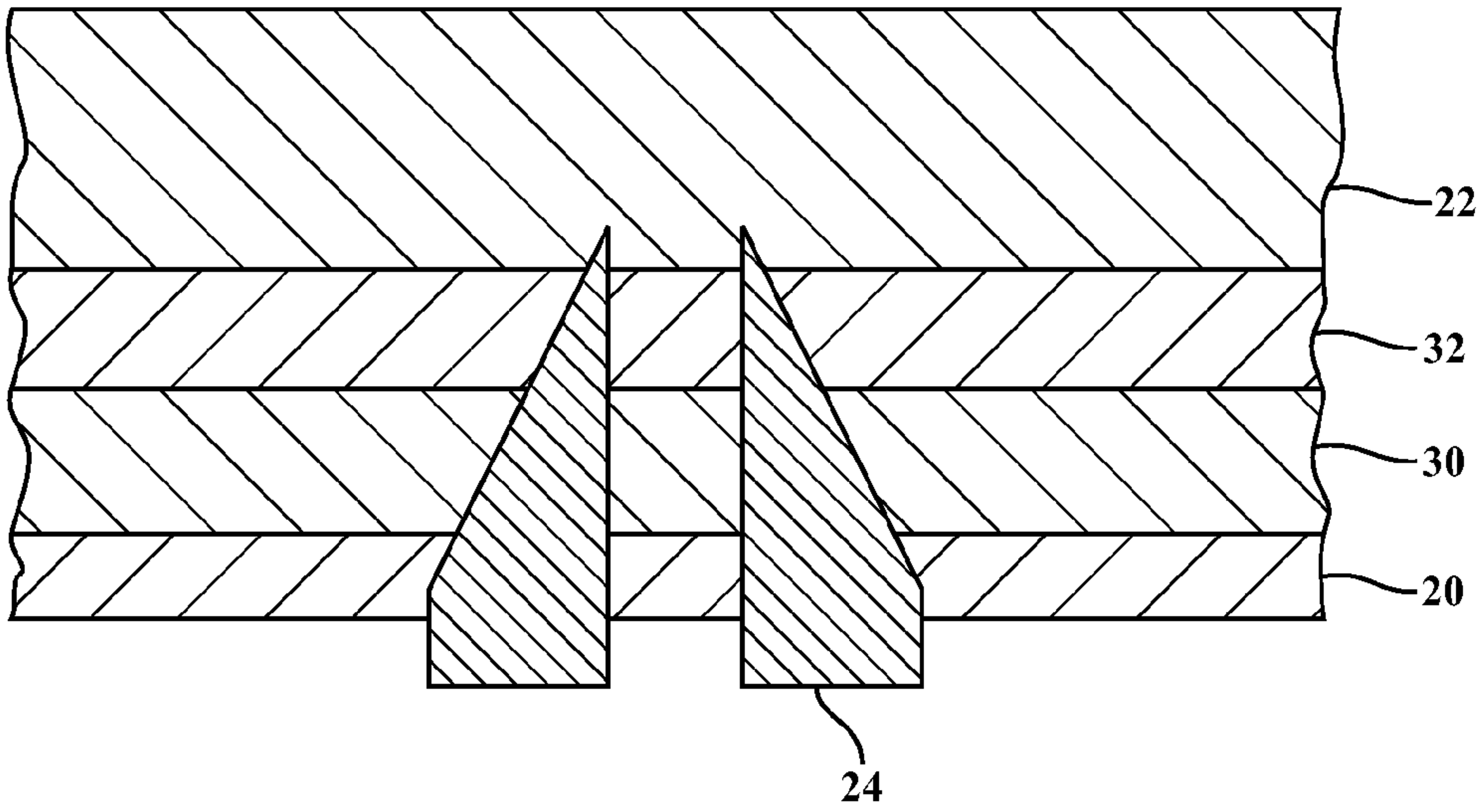


FIG. 3

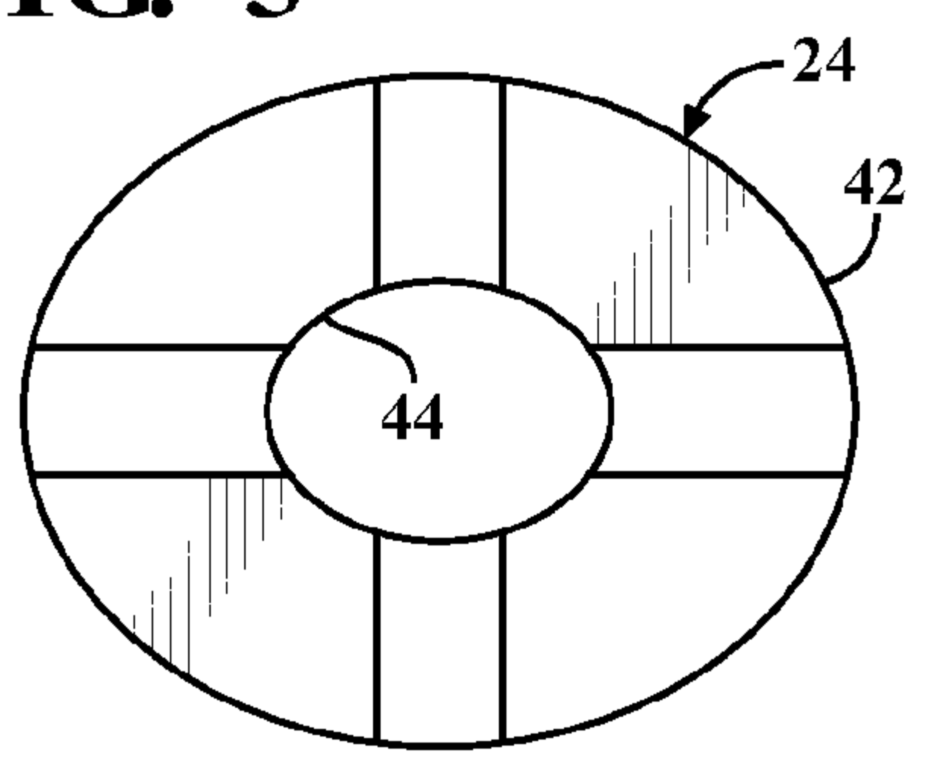
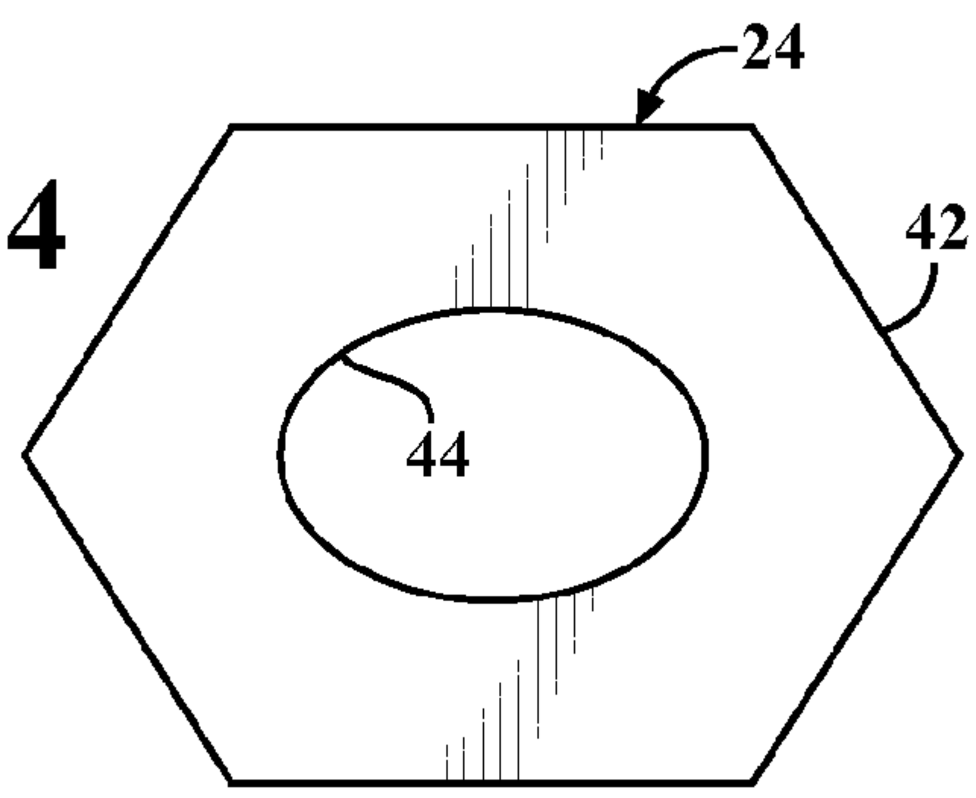


FIG. 4



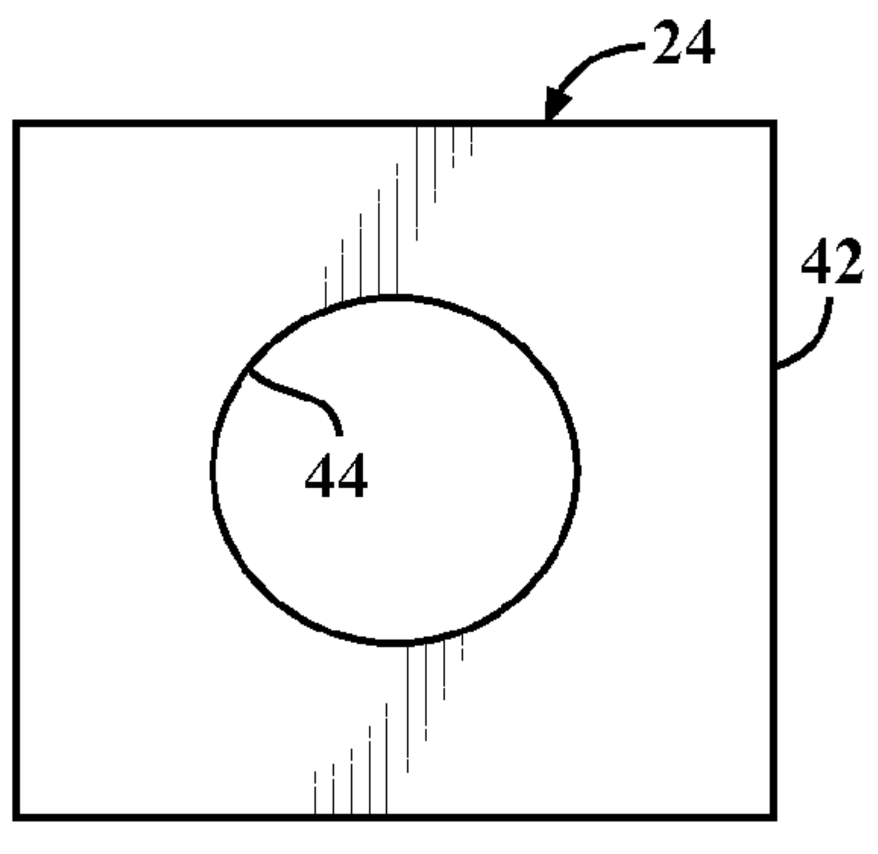


FIG. 5

FIG. 6

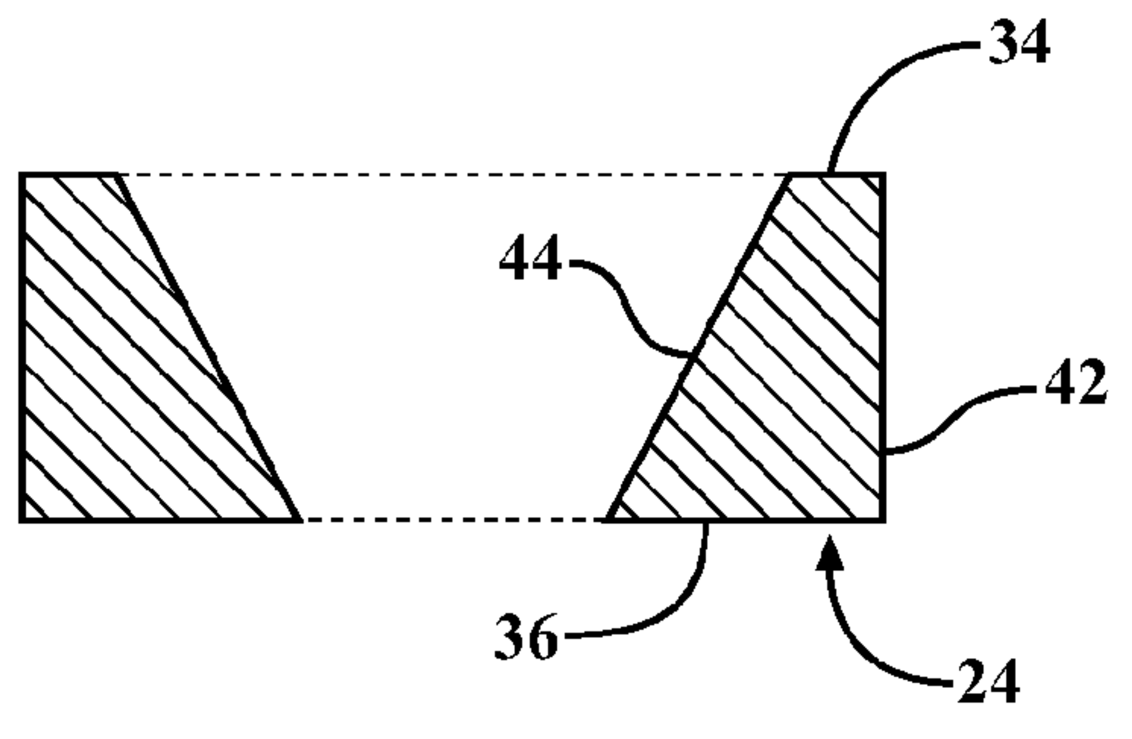


FIG. 7

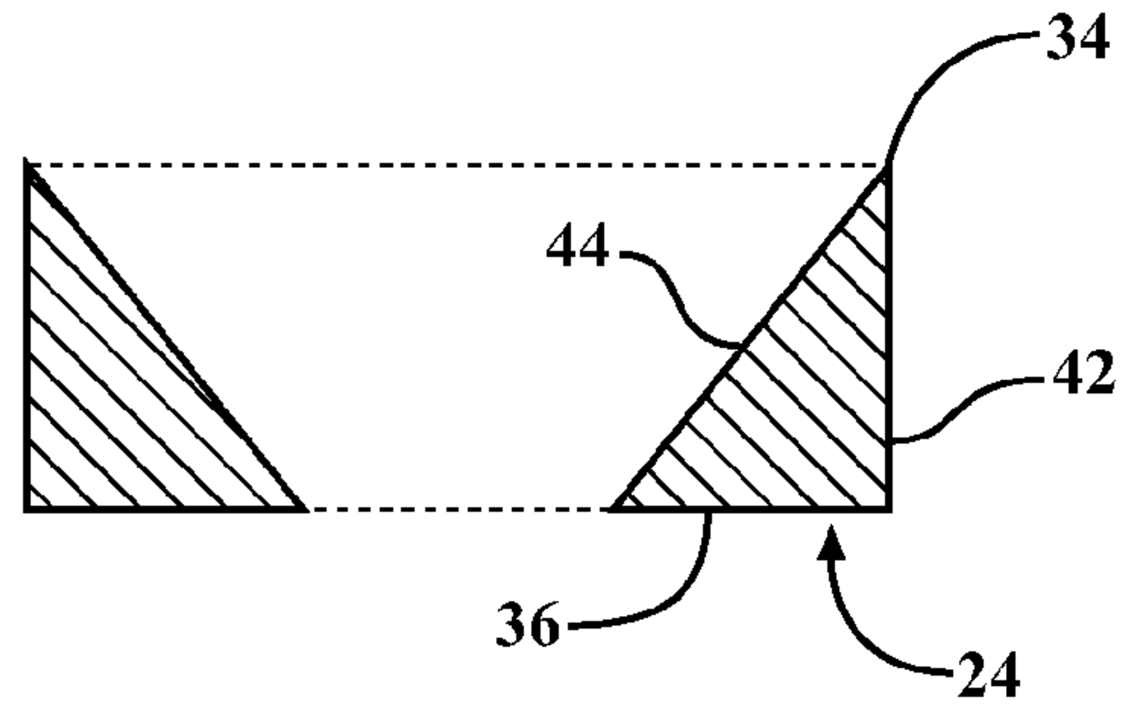
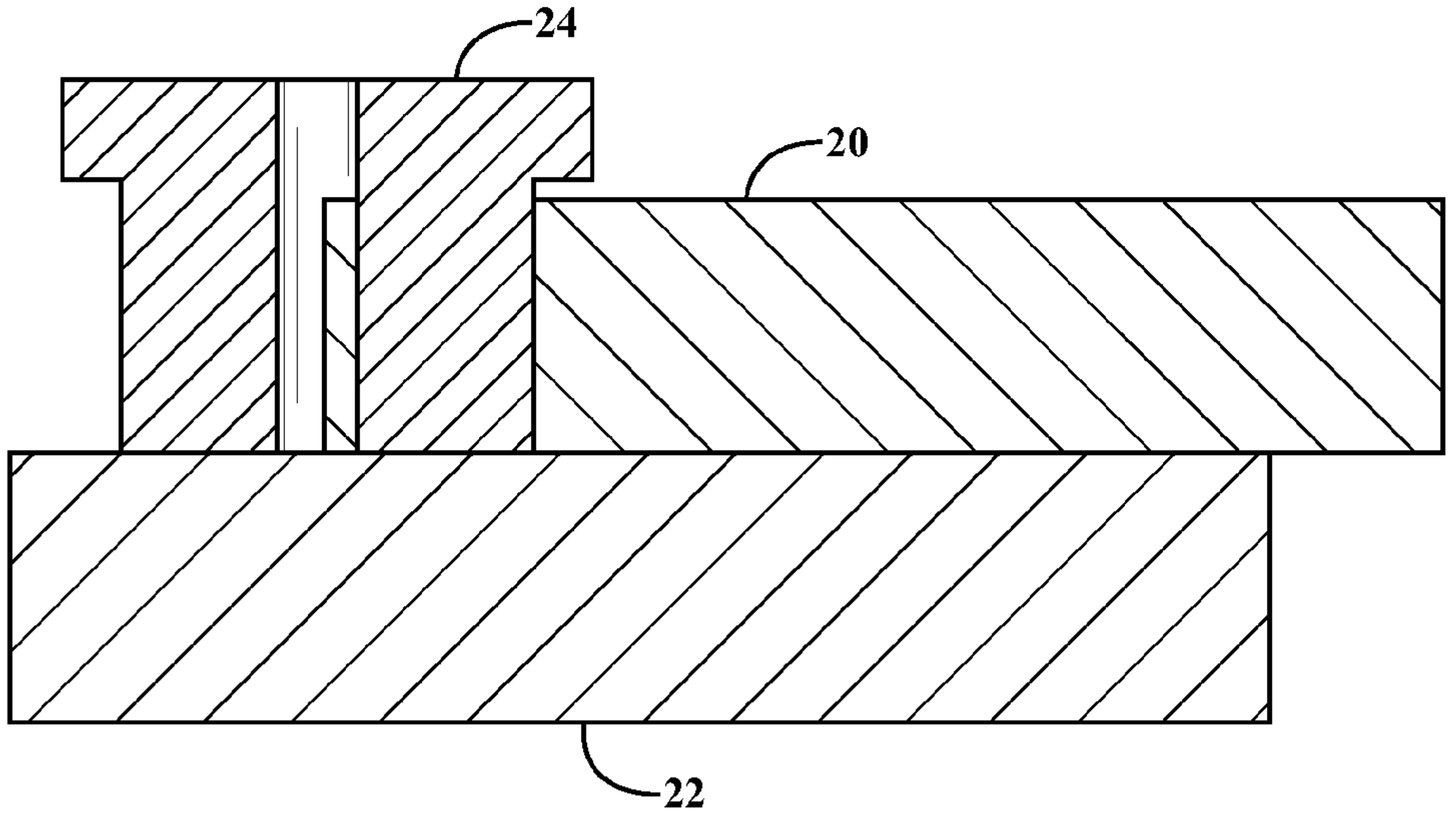


FIG. 8



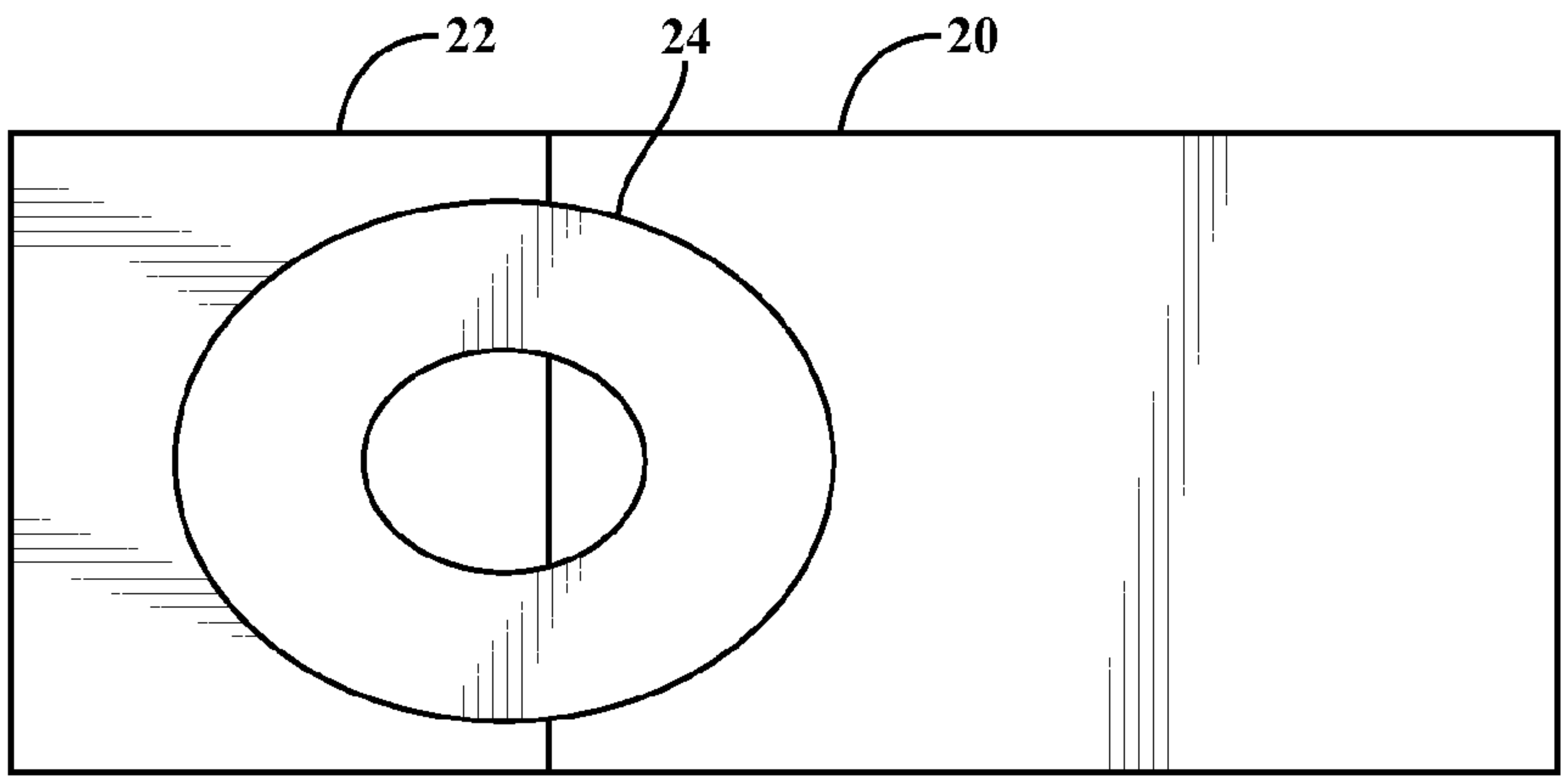
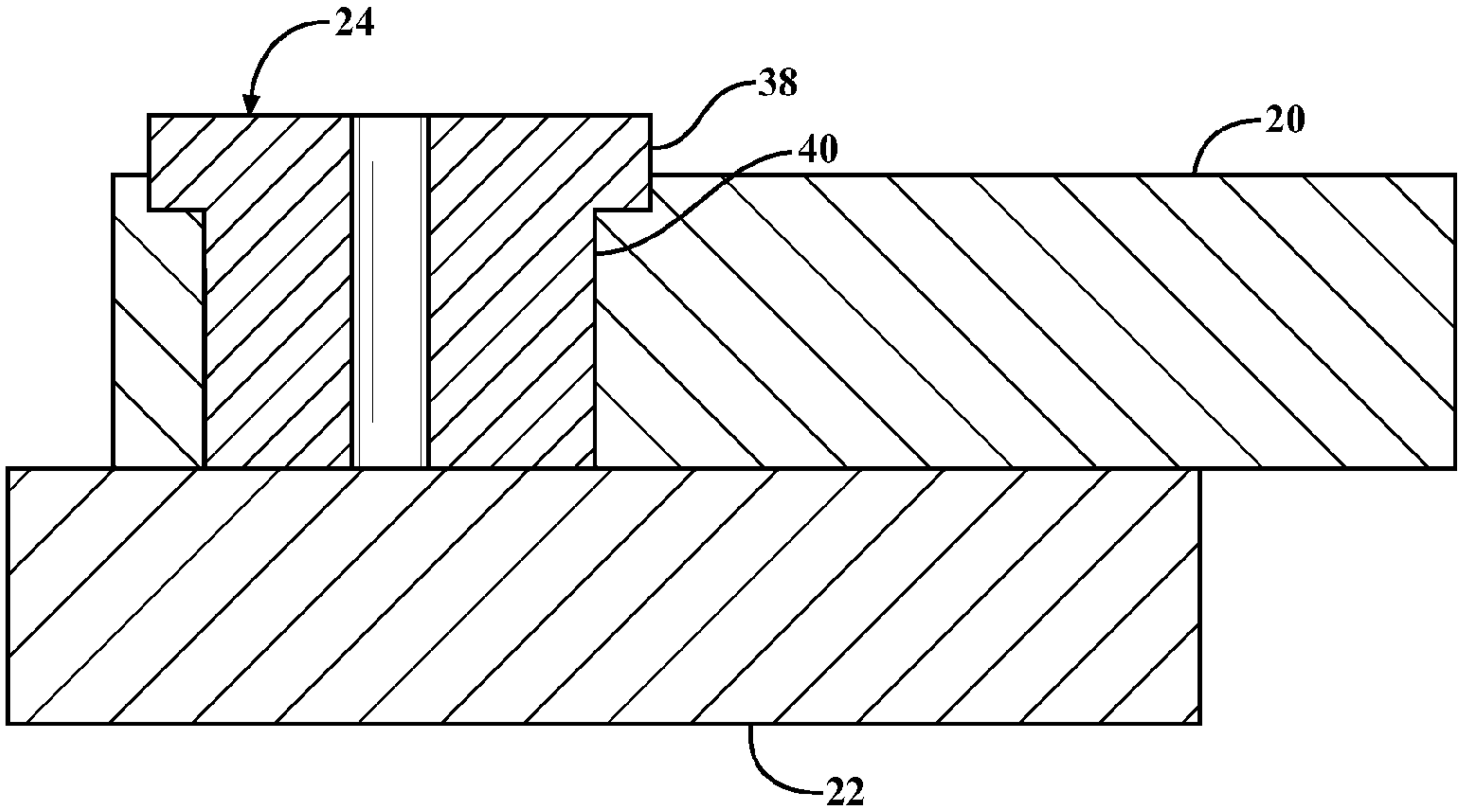


FIG. 8A

FIG. 9



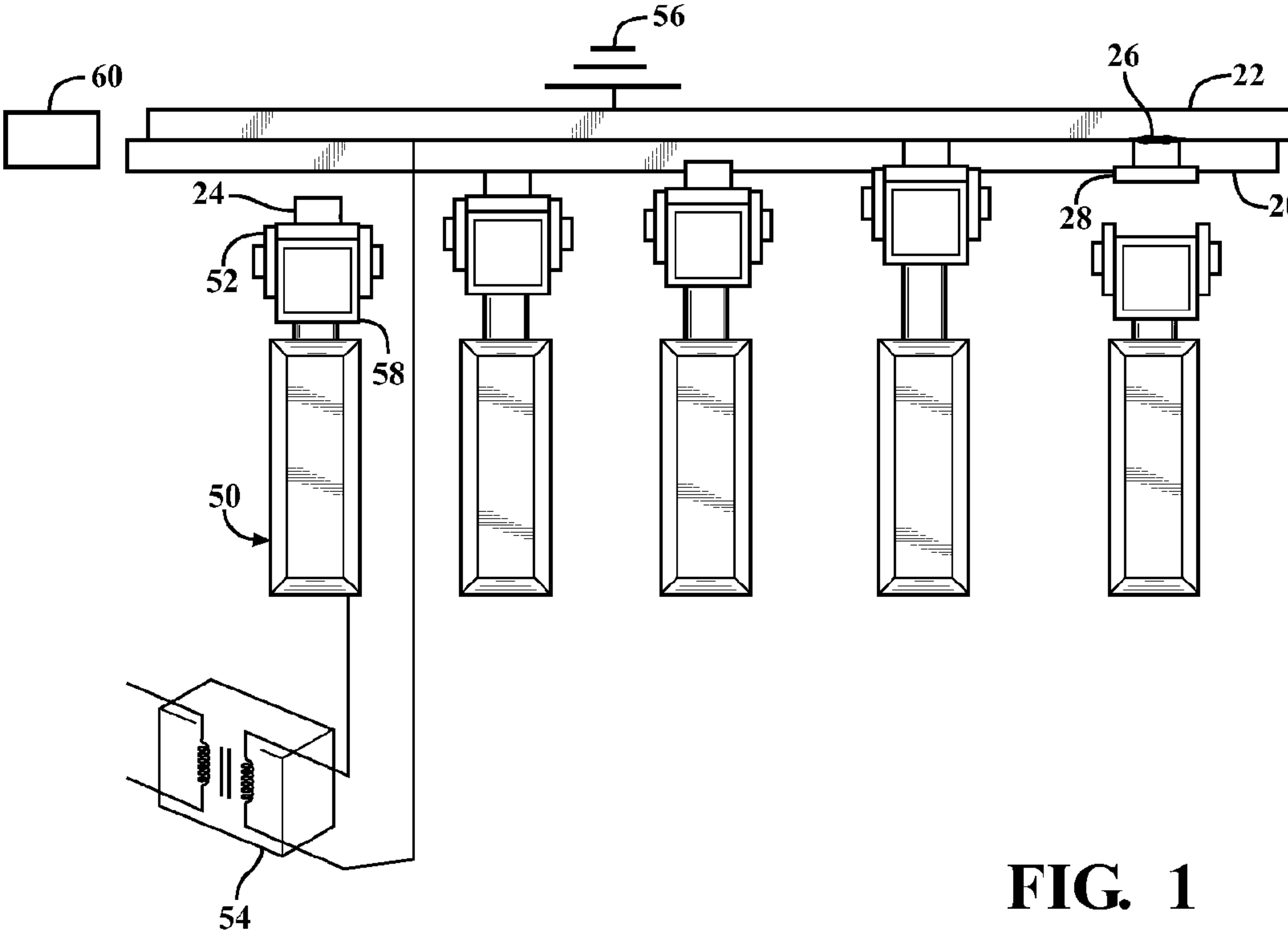


FIG. 1