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(54) **OPEN COIL EMP APPARATUS**

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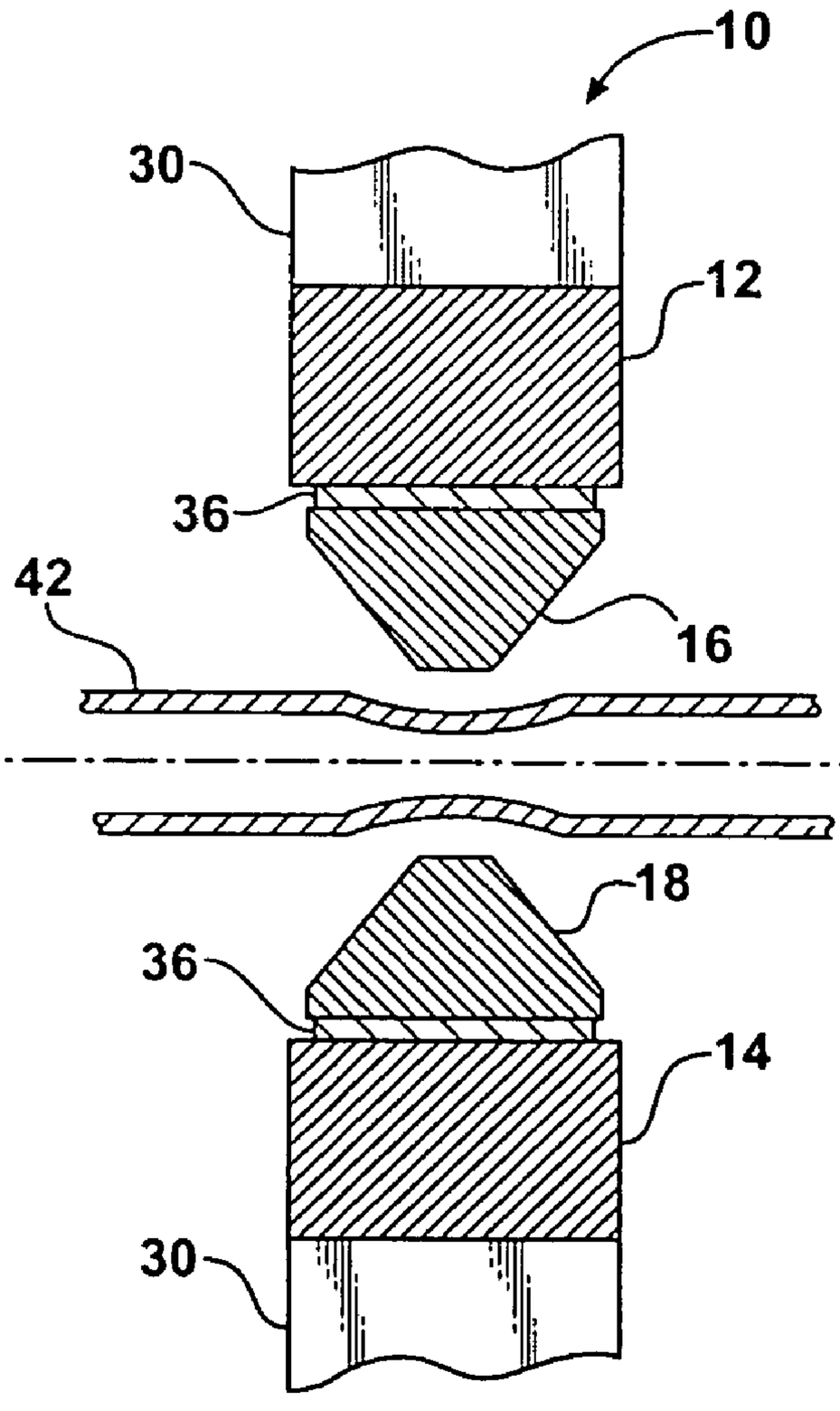
(57) **ABSTRACT**

An EMP apparatus includes first and second opposed field shaper segments. The field shaper segments include opposed working portions. First and second coil segments respectively support the first and second opposed field shaper segments. The coil segments are electrically operable and in eddy current contact with the field shaper segments. Insulators are disposed between the field shaper segments and the coil segments. A frame moveably supports the coil segments for movement between open and closed positions of the coil segments. Metal stock can be disposed between the shaper segment working portions by opening the shaper and coil segments.



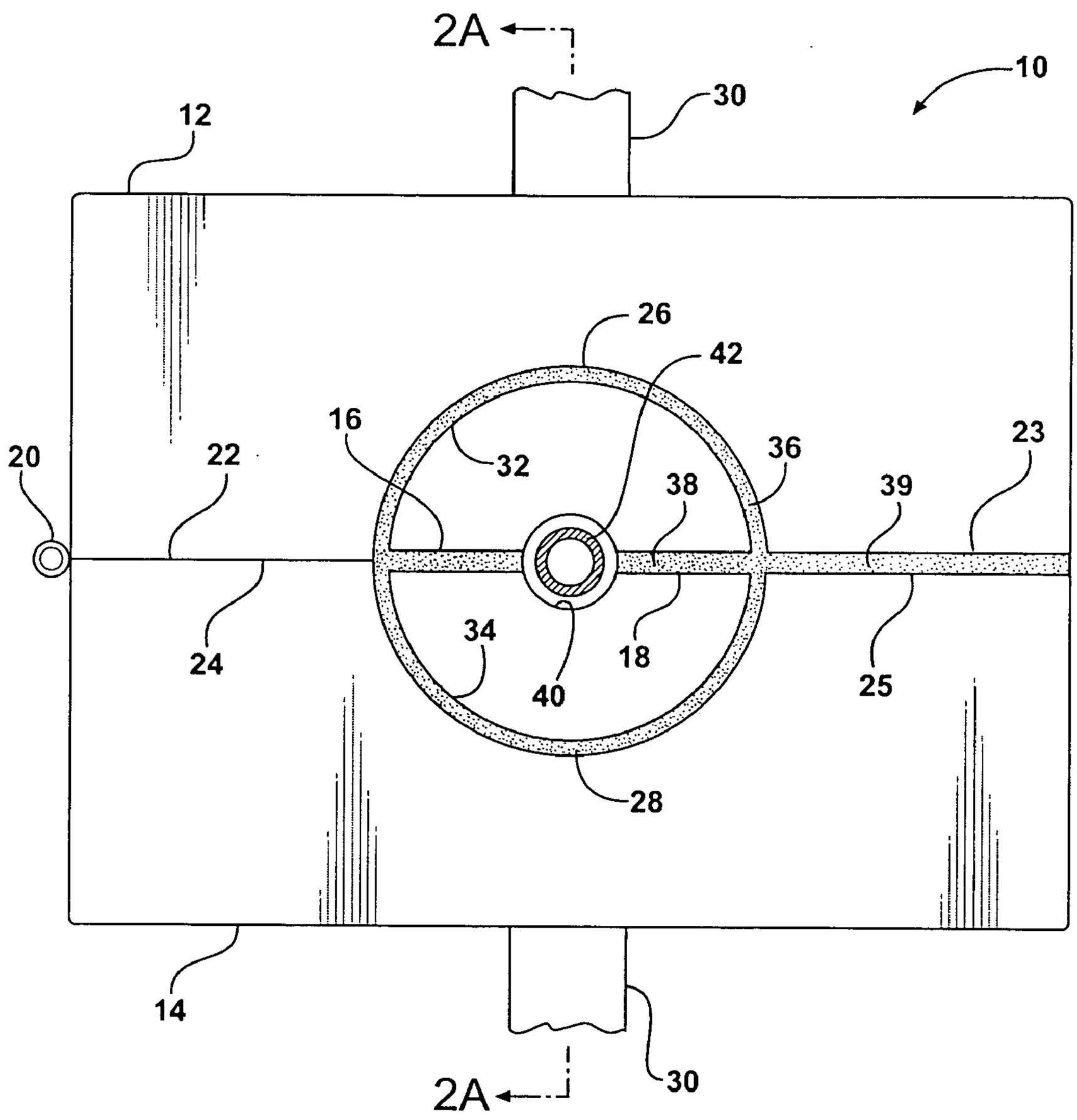


FIG - 1

FIG - 2A

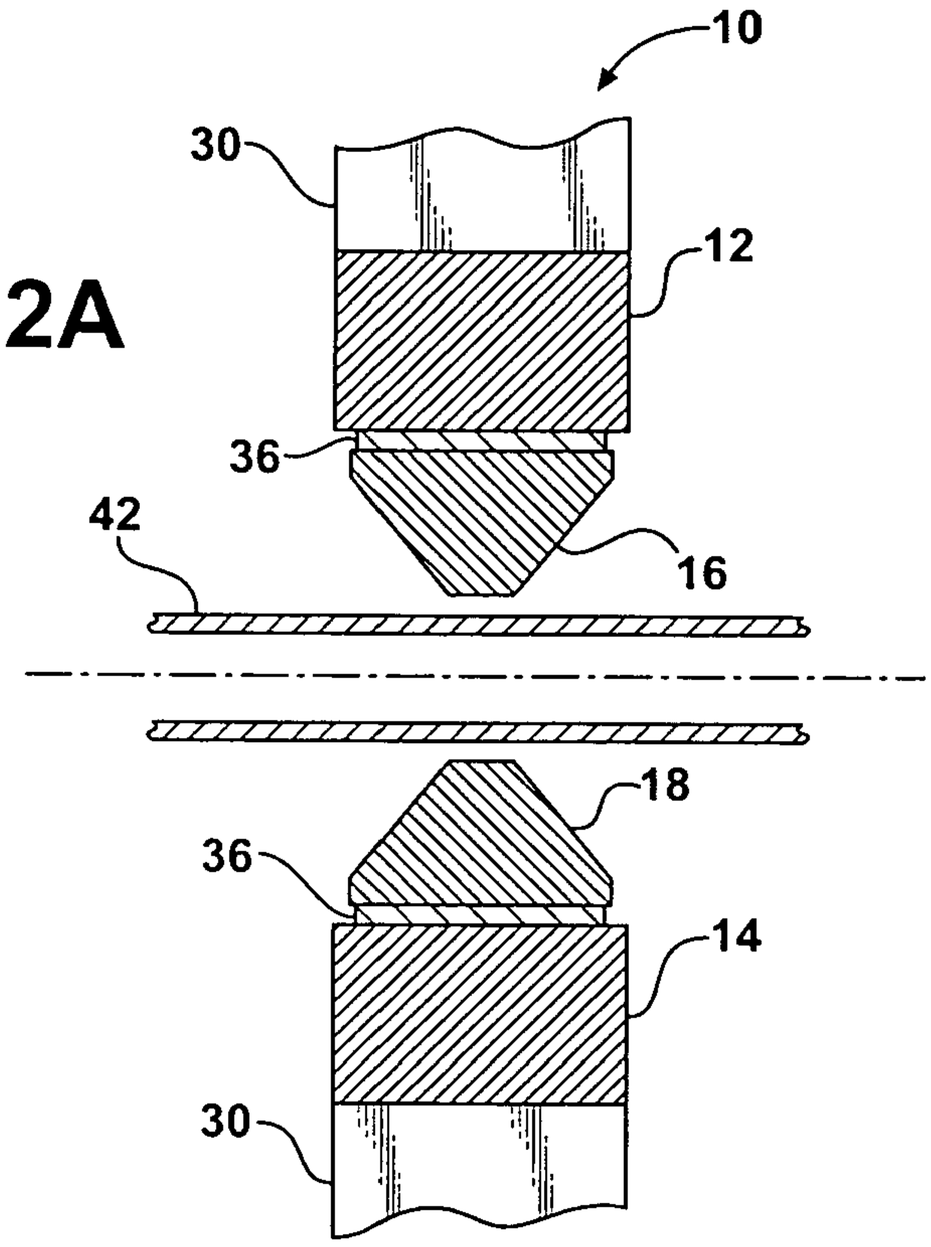
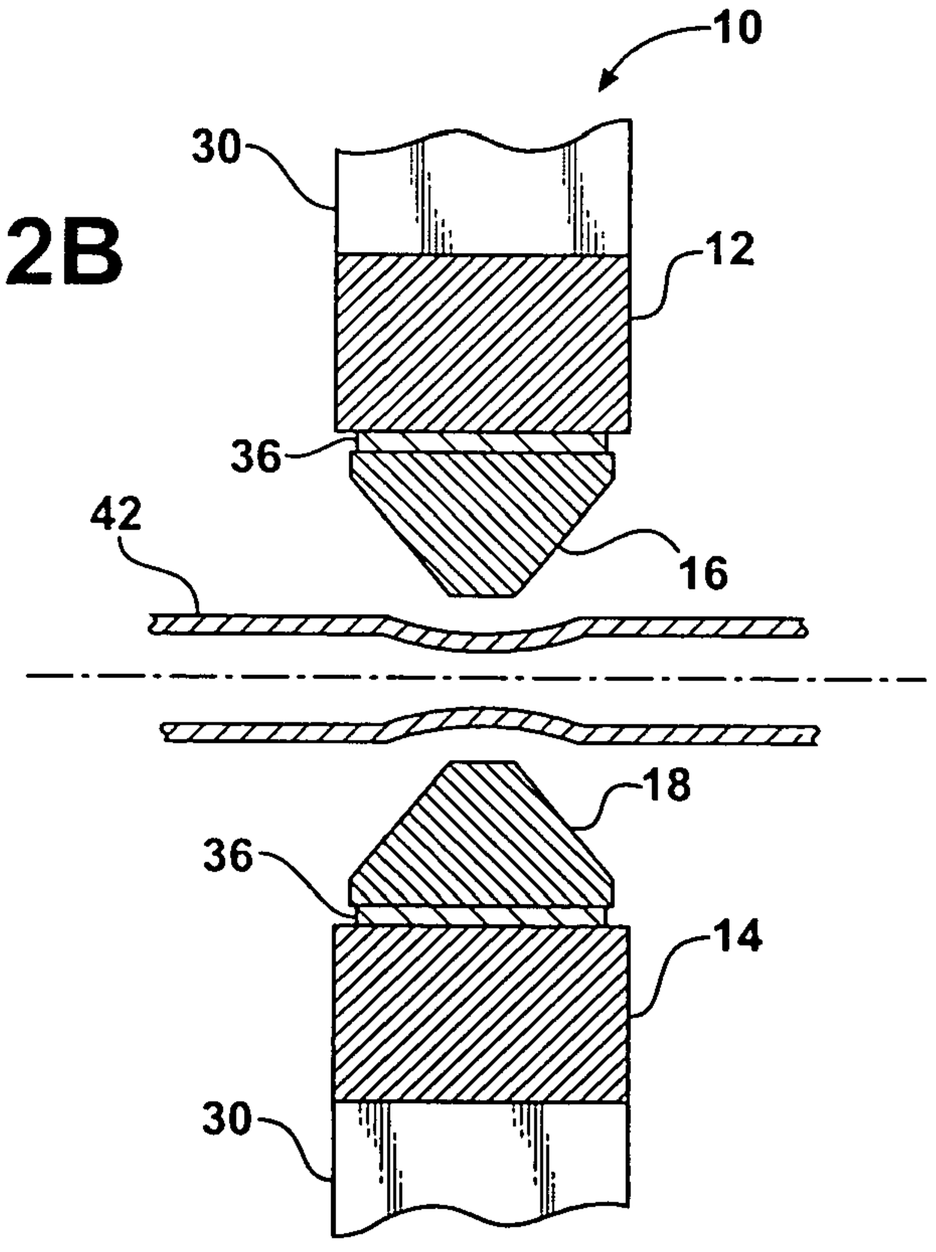


FIG - 2B



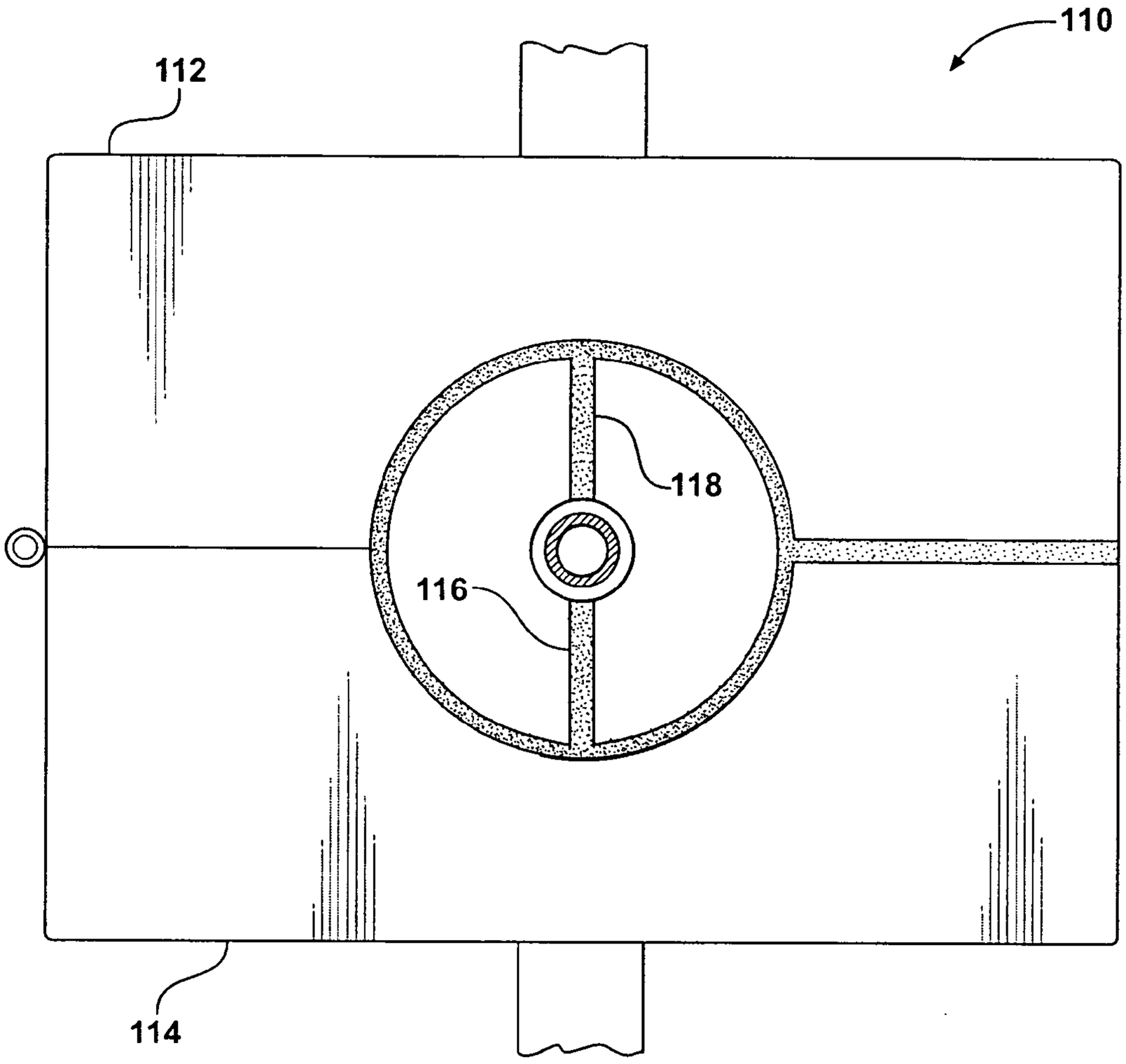
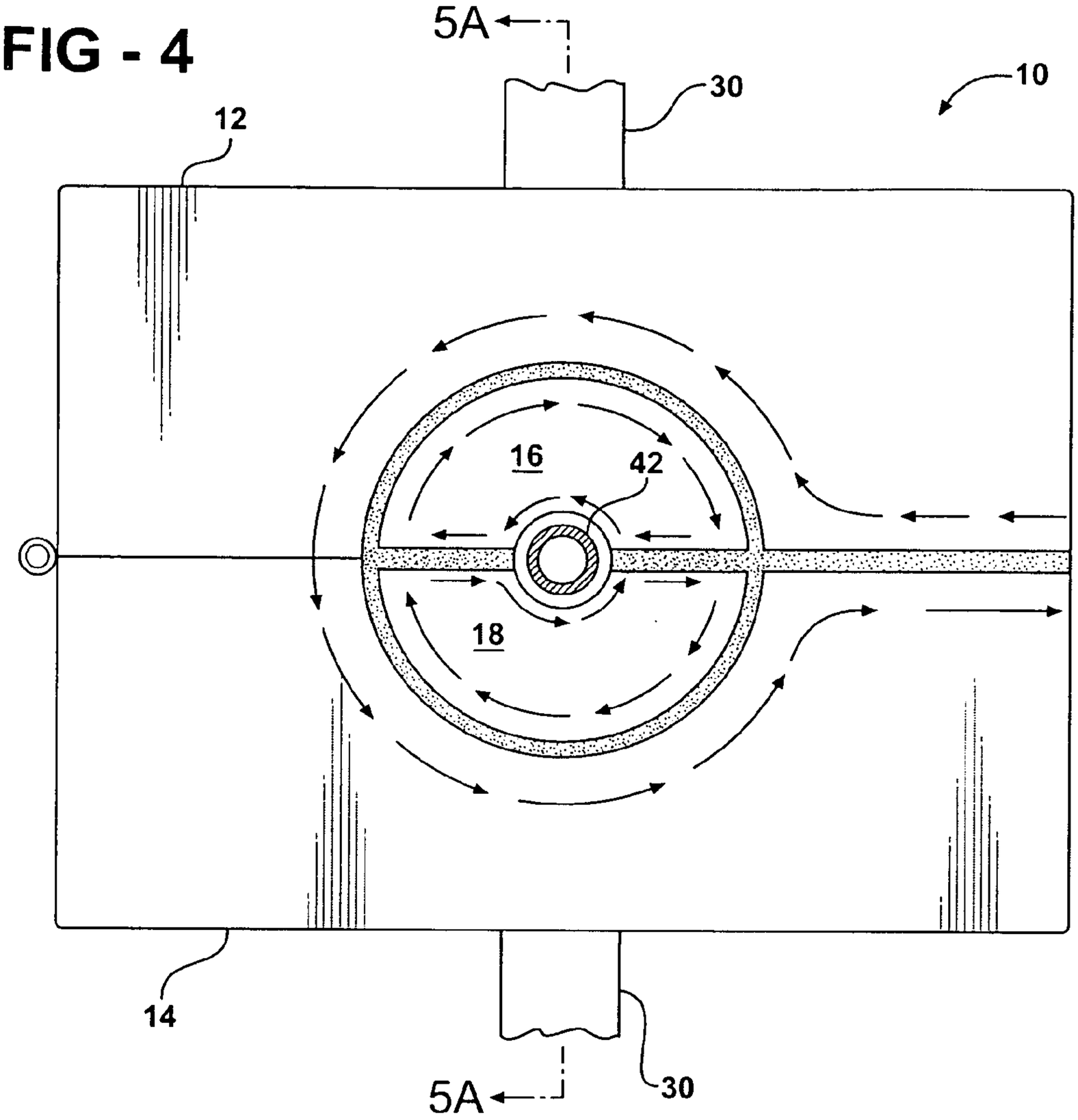


FIG - 3

FIG - 4



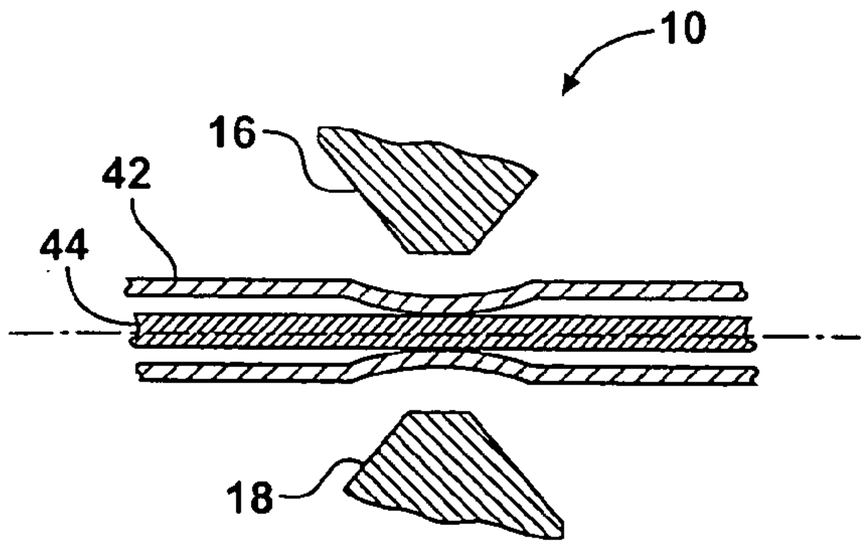


FIG - 5A

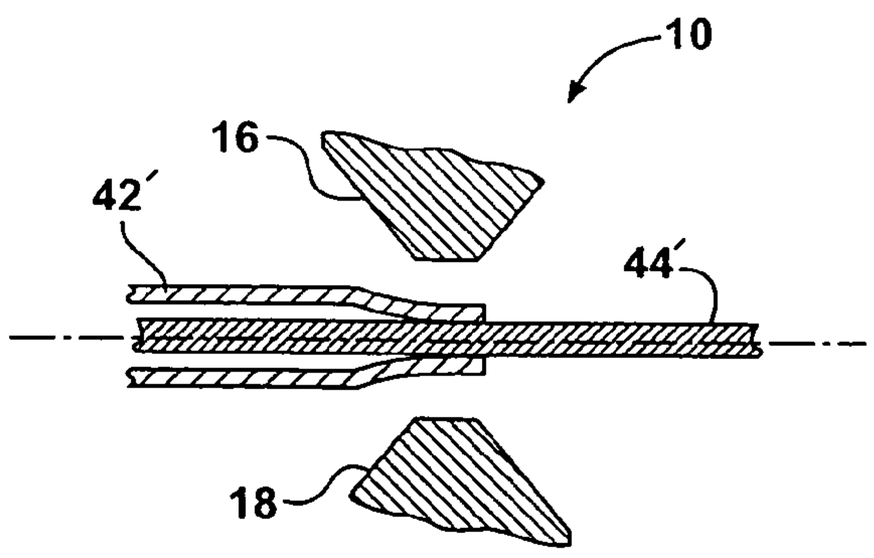


FIG - 5B

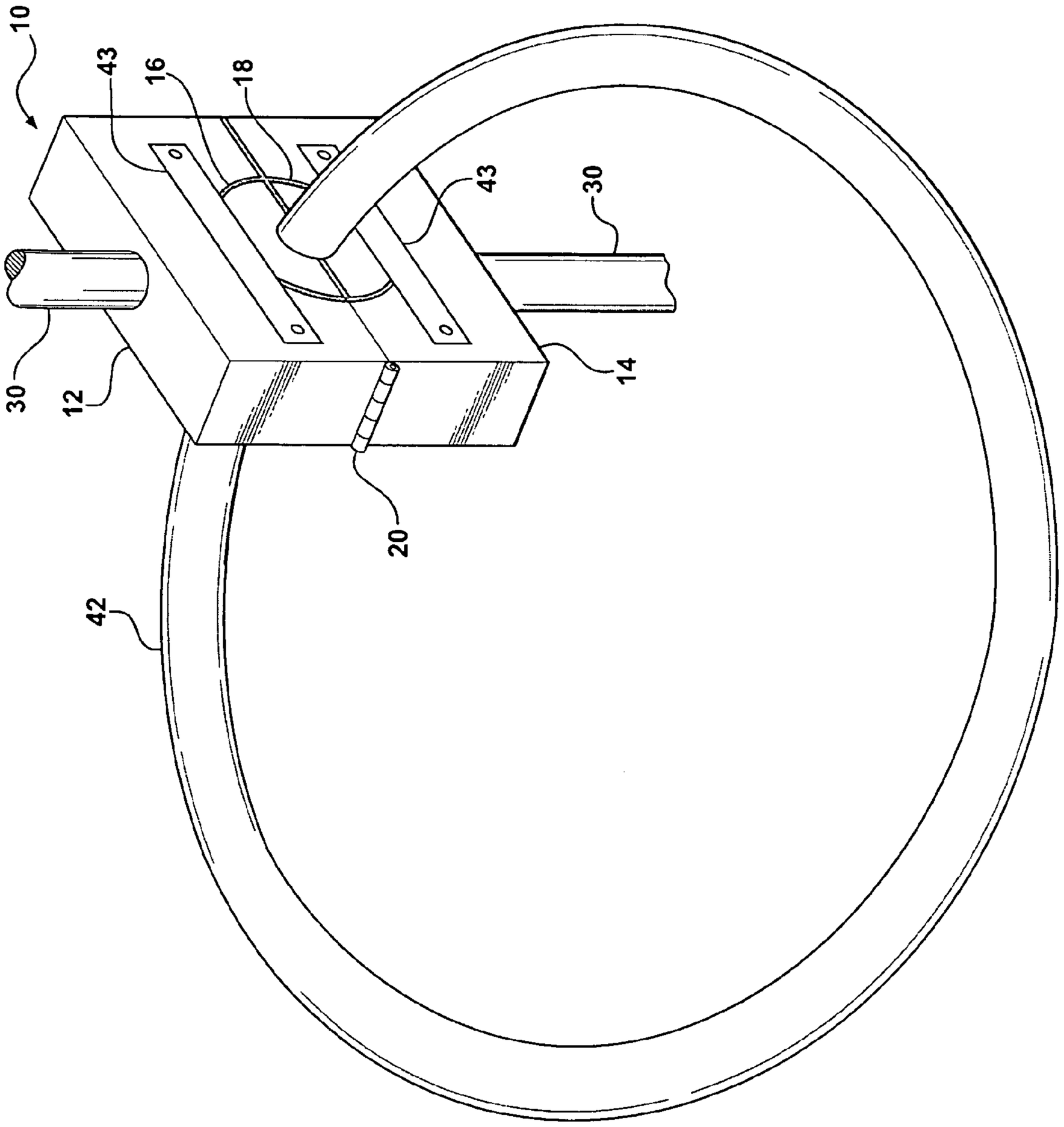


FIG - 6

OPEN COIL EMP APPARATUS

CROSS REFERENCE TO RELATED APPLICATION

[0001] This application claims the priority of U.S. Provisional Application No. 60/926,262 filed Apr. 26, 2007.

TECHNICAL FIELD

[0002] This invention relates to compression, crimping, and welding of metal tubes using an electromagnetic pulse.

BACKGROUND OF THE INVENTION

[0003] It is known in the art relating to crimping and welding to use conventional electromagnetic force apparatuses. Conventional electromagnetic coils, however, do not accommodate metal tubes having no open end or having a complex geometry.

SUMMARY OF THE INVENTION

[0004] The present invention provides for the compression, crimping, and welding of metal tubes using pulses of electromagnetic force, and more particularly to crimping and welding of metal tubes that have no open end or a complex geometry that is not accommodated by conventional electromagnetic coils.

[0005] More particularly, an open coil electromagnetic pulse ("EMP") apparatus in accordance with the invention includes first and second opposed field shaper segments. The field shaper segments include opposed working portions. First and second coil segments respectively support the first and second opposed field shaper segments. The coil segments are electrically operable and in eddy current contact with the field shaper segments, i.e., the coil segments are not in direct electrical contact with the field shaper segments, but "connected" electrically through eddy currents. Insulators are disposed between the field shaper segments and the coil segments. A frame moveably supports the coil segments for movement between open and closed positions of the coil segments. Metal stock can be disposed between the shaper segment working portions by opening the shaper and coil segments.

[0006] In one embodiment, the frame may be a clamp and may be hinged. The coil segments may be arranged in a clamshell configuration. The coil segments may have opposed curvilinear recesses and the field shaper segments may have corresponding curvilinear protrusions.

[0007] The field shaper segments may be disposed to open and close with movement of the coil segments. The field shaper segments may be disposed in a perpendicular disposition to an open and closing direction of the coil segments. A strap may be mounted on at least one of the coil segments to secure the field shaper segments in the coil segments.

[0008] A method of working a metal tube segment includes the steps of providing an EMP apparatus including first and second opposed field shaper segments, the field shaper segments including opposed working portions, first and second coil segments respectively supporting the first and second opposed field shaper segments, the coil segments being electrically operable and in eddy current contact with the field shaper segments, insulators disposed between the shaper segments and the coil segments, and a frame moveably supporting the coil segments for movement between open and closed positions of the coil segments; disposing a metal tube between the shaper segment working portions by opening the shaper and coil segments; moving the frame to move the coil segments into the closed position; applying a pulse of electric current through the coil segments to work the metal tube; and removing the metal tube by opening the shaper and coil segments.

[0009] In one embodiment, the method may also include the step of clamping the coil segments to secure the coil segments in the closed position. The frame may include a hinge for moving the coil segments between the open and closed positions. The field shaper segments may open and close with movement of the coil segments.

[0010] The method may also include the step of disposing the field shaper segments in a perpendicular disposition to an open and closing direction of the coil segments. The method may further include the step of mounting a strap on at least one of the coil segments to secure the field shaper segments in the coil segments.

[0011] These and other features and advantages of the invention will be more fully understood from the following detailed description of the invention taken together with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] In the drawings:

[0013] FIG. **1** is a side view of an open coil electromagnetic pulse apparatus in accordance with the invention;

[0014] FIG. **2**A is a cross-sectional view of the open coil electromagnetic pulse apparatus taken along the line **2**A-**2**A in FIG. **1** illustrating a metal tube workpiece prior to an electromagnetic pulse;

[0015] FIG. **2**B is a schematic, cross-sectional view similar to FIG. **2**A illustrating compression and deformation of the metal tube after an electromagnetic pulse;

[0016] FIG. **3** is a side view of an alternative embodiment of an open coil electromagnetic pulse apparatus in accordance with the invention;

[0017] FIG. **4** is a schematic view of primary and induced currents in coil segments, field shapers, and metal tube of FIG. **1**;

[0018] FIGS. **5**A and **5**B are schematic views of electromagnetic crimping or welding using the electromagnetic pulse apparatus of the present invention; and

[0019] FIG. **6** is an environmental view of the electromagnetic pulse apparatus working on metal stock.

DETAILED DESCRIPTION OF THE INVENTION

[0020] Referring now to the drawings in detail, numeral **10** generally indicates an open coil EMP apparatus in accordance with the invention. The open coil EMP apparatus **10** provides for electromagnetic pulse crimping and welding of metal workpieces that have no open end or a complex geometry, for example a tubular ring, a bicycle frame, a motorcycle frame, a automobile frame, or similar.

[0021] With reference to FIGS. **1**, **2**A, **2**B, **4**, and **6**, in accordance with a first embodiment an open coil EMP apparatus **10** includes two coil segments **12**, **14** forming an open coil, and two field shaper segments **16**, **18**. The coil segments **12**, **14** may be in a contact position (a "closed position") as shown in FIG. **1** or may be separated from each other (an "open position") to allow for insertion of a workpiece (e.g., metal stock) into the open coil as described in more detail below. The coil segments **12**, **14** also may be connected at one

end by a hinge **20** to allow for pivotal movement of the coil segments between the closed, contact position and the open, separated position. In the closed position, a contact surface **22** of the coil segment **12** and a contact surface **24** of the coil segment **14** contact each other, allowing for flow of current between the coil segments as described in more detail below. Further, in the closed position, a non-contact surface **23** of coil segment **14** and a non-contact surface **25** of coil segment **16** are spaced from each other. The coil segments **12**, **14** also include opposed curvilinear recesses **26**, **28**, and in the closed position the curvilinear recesses of the coil segments define a cavity within the coil segments.

[0022] A frame **30** moveably supports the coil segments **12**, **14** for movement between the open and closed positions. The frame **30** may be a clamp that secures the coil segments **12**, **14** in the closed position and prevents the coil segments from moving or separating when the coils are actuated as described below.

[0023] The field shaper segments **16**, **18** are supported by the coil segments **12**, **14** and are generally disposed in the cavity defined by the coil segments. The field shaper segments **16**, **18** may be disposed so as to open and close with the movement of the coil segments **12**, **14**. The field shaper segments **16**, **18** have curvilinear protrusions **32**, **34** that correspond to the curvilinear recesses **22**, **24** of the coil segments **12**, **14**, respectively. An insulator **36** is disposed between the field shaper segments **16**, **18** and the coil segments **12**, **14**. The insulator **36** may be a thin layer of kapton tape, a non-conductive polymer, or similar. Field shaper segment **16** does not contact field shaper segment **18**. An insulator **38** such as a thin layer of kapton tape, non-conductive polymer or similar may be disposed between field shaper segment **16** and field shaper segment **18**. Similarly, an insulator **39** such as a thin layer of kapton tape, non-conductive polymer or similar may be disposed between the non-contact surfaces **23**, **25** of the coil segments **12**, **14**.

[0024] The field shaper segments **16**, **18** define an opening **40** that extends through the field shaper segments. The opening **40** may be cylindrical/tubular in shape and is sized in such a way to be adapted to receive a metal workpiece **42** such as a tubular metal workpiece or other metal stock therethrough. To insert the metal tube **42** in the apparatus, the coil segments **12**, **14** may be separated from each other, the metal tube may be placed between the field shaper segments **16**, **18**, and then the coil segments may be returned to the closed position. When the metal tube **42** is placed in the opening **40**, it is ready to be crimped or welded by the open coil apparatus **10**. Further, in the closed position a strap **43** may be mounted on at least one of the coil segments **12**, **14** to secure the field shaper segments **16**, **18** in the coil segments.

[0025] To crimp or weld the metal tube **42**, a brief, high intensity pulse of electrical current is passed through the coil segments **12**, **14** via the contact surfaces **22**, **24**, thereby temporarily generating an electromagnetic field around the coil segments. For example, the current pulse may be in the range of 5-500 kA lasting for a duration of 0.1-100 milliseconds, and may be supplied by a power source such as a charged capacitor bank or similar power source capable of providing a current pulse within the stated ranges.

[0026] The generated electromagnetic field induces an eddy current in the field shaper segments **16**, **18**. In turn, the eddy current in the field shaper segments **16**, **18** generates an electromagnetic field that induces an eddy current in the target metal tube **42**. The eddy current induced in the metal tube **42** produces an electromagnetic field that opposes the electromagnetic field of the field shaper segments **16**, **18**. The field shaper segments **16**, **18** are positioned relative to the metal tube **42** such that the opposing electromagnetic fields cause the walls of the metal tube to accelerate away from the field shaper segments, thereby compressing the metal tube without physically contacting the tube. The repulsive force generated by the electromagnetic field of the field shaper segments **16**, **18** is therefore a non-contact force. The frame **30** prevents the coil segments **12**, **14** from opening due to the magnetic force during the electromagnetic pulse, and also prevents arcing between the contact surfaces **22**, **24** during the pulse by keeping the contact surfaces from separating.

[0027] After the compression, crimping, or welding has been performed on the metal tube **42**, the frame **20** may be opened, separating the coil segments **12**, **14** to allow the metal tube to be removed from the apparatus.

[0028] In an alternative arrangement of the apparatus **110**, as shown in FIG. **3** the orientation of the slot between field shaper segment **116** and field shaper segment **118** may be disposed in any direction, and not necessarily in the orientation shown in FIG. **1**. For example, in FIG. **1** the slot between the field shaper segments **16**, **18** is generally parallel (i.e., aligned) with a separation line between the coil segments **12**, **14**. In contrast, in FIG. **3** the slot between the field shaper segments **116**, **118** is generally perpendicular to a separation line between the coil segments **112**, **114**. The field shape segments **116**, **118** are also disposed in a perpendicular disposition to an open and closing direction of the coil segments **112**, **114**. In this orientation, the force along the slot between the field shaper segments **116**, **118** is reduced because the repulsive forces that arise during an electromagnetic pulse act on the field shaper segments in a different direction than the coil segments **112**, **114**. Therefore, it is easier to keep the coil segments **112**, **114** in the closed position during an electromagnetic pulse. It should be understood that the slot between the field shaper segments may be disposed at any angle relative to the separation line between the coil segments.

[0029] FIGS. **5**A and **5**B illustrate electromagnetic pulse crimping or welding using the open coil apparatus **10**. As shown schematically, the metal tube **42** may be deformed by the electromagnetic forces and moves towards an inner metal piece **44**. The deformed area of the metal tube **42** collides with the metal piece **44**, and is crimped or welded together with metal piece depending on the collision velocity. The metal piece **44** may be a rod, tube, or similar. FIG. **5**A illustrates center joining of the metal tube **42** to the metal piece **44**, while FIG. **5**B illustrates end joining of a metal tube **42'** and metal piece **44'**.

[0030] Although the invention has been described by reference to specific embodiments, it should be understood that numerous changes may be made within the spirit and scope of the inventive concepts described. Accordingly, it is intended that the invention not be limited to the described embodiments, but that it have the full scope defined by the language of the following claims.

What is claimed is:

1. An EMP apparatus comprising:

first and second opposed field shaper segments;

said field shaper segments including opposed working portions;

first and second coil segments respectively supporting said first and second opposed field shaper segments;

said coil segments being electrically operable and in eddy current contact with said field shaper segments;

insulators disposed between said field shaper segments and said coil segments; and

a frame moveably supporting said coil segments for movement between open and closed positions of said coil segments;

whereby metal stock can be disposed between said shaper segment working portions by opening said shaper and coil segments.

2. The EMP apparatus of claim **1**, wherein said frame is a clamp.

3. The EMP apparatus of claim **1**, wherein said frame is hinged.

4. The EMP apparatus of claim **3**, wherein said coil segments are arranged in a clamshell configuration.

5. The EMP apparatus of claim **1**, wherein coil segments have opposed curvilinear recesses and said field shaper segments have corresponding curvilinear protrusions.

6. The EMP apparatus of claim **1**, wherein said field shaper segments are disposed to open and close with movement of said coil segments.

7. The EMP apparatus of claim **1**, wherein said field shaper segments are disposed in a perpendicular disposition to an open and closing direction of said coil segments.

8. The EMP apparatus of claim **1**, including a strap mounted on at least one of said coil segments to secure said field shaper segments in said coil segments.

9. A method of working a metal tube segment comprising the steps of:

providing an EMP apparatus including:

first and second opposed field shaper segments;

said shaper segments including opposed working portions;

first and second coil segments respectively supporting said first and second opposed field shaper segments;

said coil segments being electrically operable and in eddy current contact with said field shaper segments;

insulators disposed between said shaper segments and said coil segments; and

a frame moveably supporting said coil segments for movement between open and closed positions of said coil segments;

disposing a metal tube between said shaper segment working portions by opening said shaper and coil segments;

moving said frame to move said coil segments into said closed position;

applying a pulse of electric current through said coil segments to work said metal tube; and

removing said metal tube by opening said shaper and coil segments.

10. The method of claim **9**, including the step of:

clamping said coil segments to secure said coil segments in said closed position.

11. The method of claim **9**, wherein said frame includes a hinge for moving said coil segments between said open and closed positions.

12. The method of claim **9**, wherein said field shaper segments open and close with movement of said coil segments.

13. The method of claim **9**, including the step of:

disposing said field shaper segments in a perpendicular disposition to an open and closing direction of said coil segments.

14. The method of claim **9**, including the step of:

mounting a strap on at least one of said coil segments to secure said field shaper segments in said coil segments.

* * * * *