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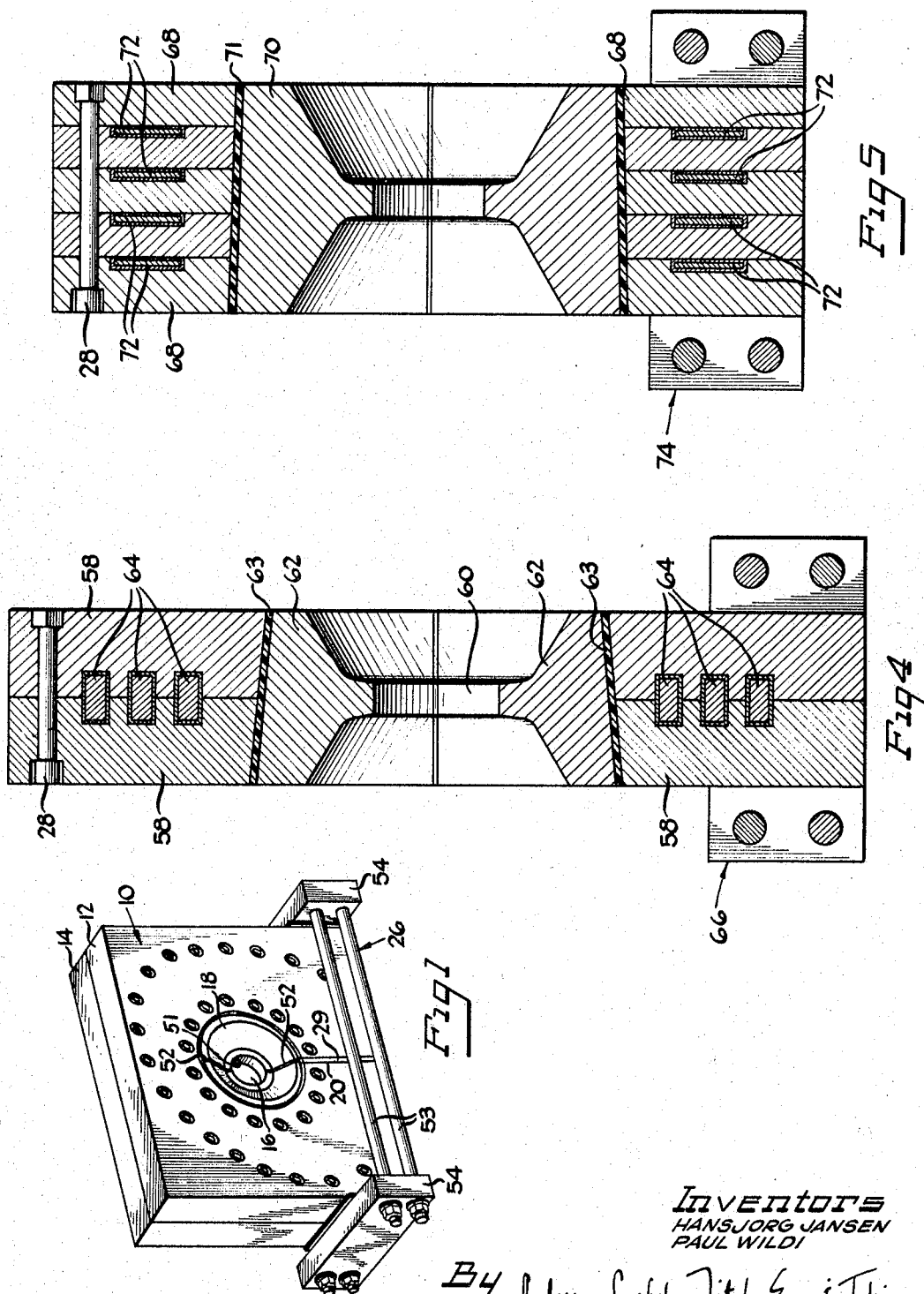
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COIL FOR MAGNETIC FORMING

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2 Sheets-Sheet 1



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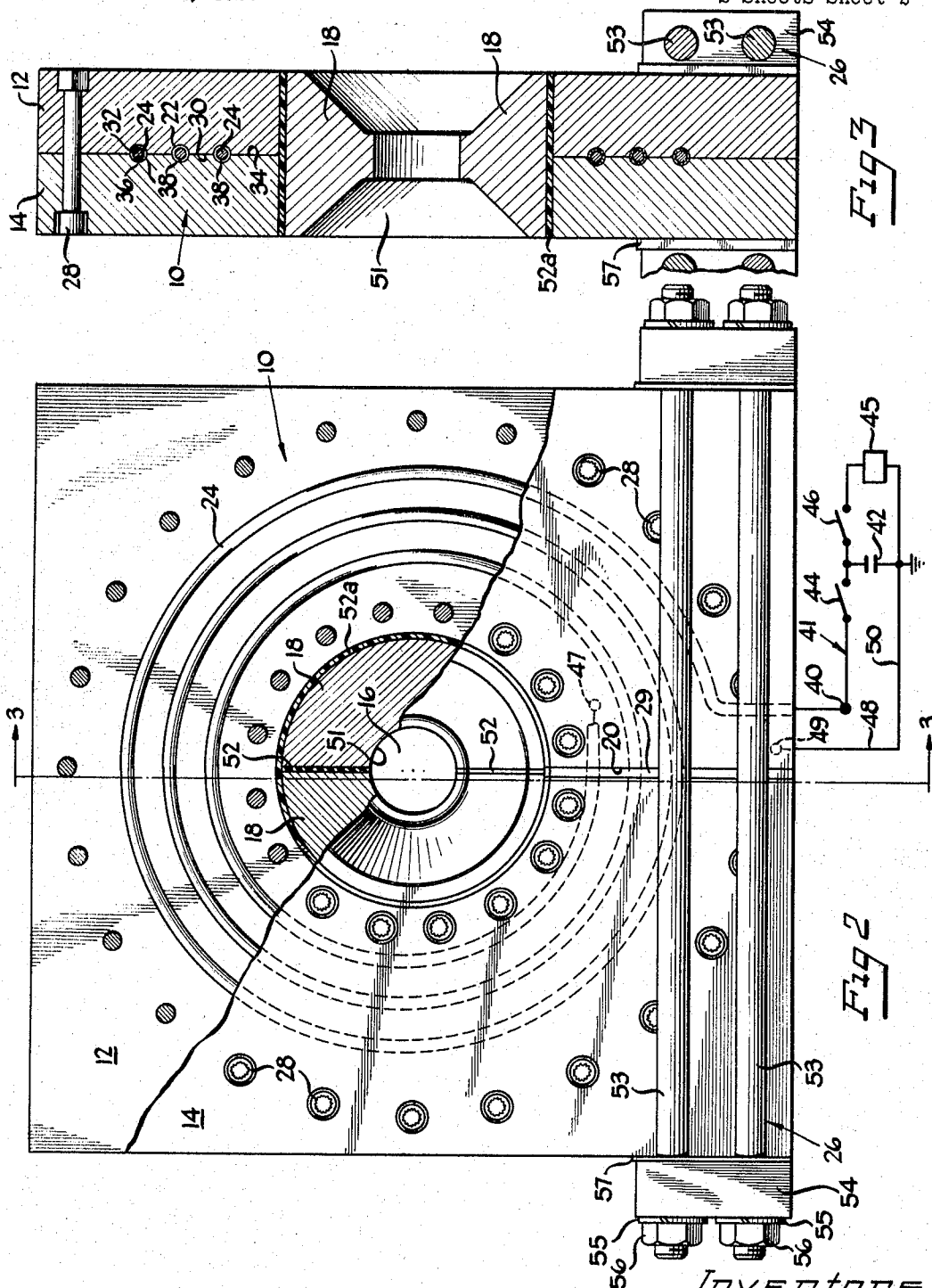
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COIL FOR MAGNETIC FORMING

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8 Claims. (Cl. 72—56)

The present invention relates to electromagnetic forming and, more particularly, is directed to an improved coil assembly for use in an electromagnetic forming apparatus.

Methods and apparatus for forming materials through the utilization of energy furnished by an intense magnetic field have found considerable application. For example, such apparatus has been used for forming a conductive workpiece into desired shapes. This is accomplished by generating an intense magnetic field for inducing current flow in the workpiece. The resulting interaction between the induced current and the magnetic field subjects the workpiece to a force varying with the intensity of the magnetic field. By appropriately restraining motion of the workpiece, this applied force effects the deformation of the workpiece into a desired shape.

Considerable difficulties have been encountered in the design and operation of coil structures suitable for use in magnetic forming operations. In the first place, in a conventional magnetic forming coil structure in which a primary winding is helically wound about a generally cylindrical metallic coil body, the magnetic forces on the winding are not balanced. Instead, a net force is present which urges the primary winding away from the coil body, thus stretching the winding and fatiguing the metal.

These forces are partially compensated for by layers of insulation such as resin-impregnated glass fibers with which the outside of the primary winding is wrapped. Due to the difference in the elastic properties between the windings and insulation, however, this insulation is only moderately effective in providing structural support.

An additional source of difficulty arises from the fact that only a portion of the circumference of the primary winding is utilized for current carrying purposes. This results in increased resistive and magnetic leakage losses and also results in a higher inductance than is otherwise necessary.

Accordingly, it is an object of the present invention to provide an improved coil assembly suitable for use in high intensity pulsed magnetic field operations.

Another object of the invention is the provision of a coil assembly in which the conductive windings are suitably reinforced without detracting from their electrical efficiency.

Still a further object of the invention is the provision of an improved compact coil assembly which is relatively simple to manufacture and possesses substantial mechanical strength.

Other objects and advantages of the present invention will become apparent from the following detailed description when considered in conjunction with the accompanying drawings wherein:

FIGURE 1 is a perspective view of a coil assembly showing various of the features of the invention;

FIGURE 2 is a partially broken away elevational view of the coil assembly of FIGURE 1;

FIGURE 3 is a sectional view taken along line 3—3 of FIGURE 2; and

FIGURES 4 and 5 are sectional views similar to that of FIGURE 3, but showing alternate forms of construction.

In general, the coil assembly shown in the drawings includes a coil body 10 formed of a pair of flat slabs 12 and 14 disposed in face-to-face relation. The coil body,

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as defined by the slabs, includes a central opening 16 having disposed therein a field shaping element 18 which is adapted to receive a workpiece (not shown). An insulation filled slit 20 extends from the central opening 16 to a peripheral edge of the coil body to allow a magnetic field to be established in the opening. The adjacent faces of the slabs 12 and 14 are each provided with a spiral groove which cooperate with each other to define a spiral bore 22 within which a spiral arranged primary winding 24 is disposed. Hence, the winding 24 is virtually completely encased in, and surrounded by, the coil body 10.

When a high amperage pulse of current is passed through the primary winding 24, a current is induced in the coil body 10, which, in turn, generates a field which induces a current in the field shaper 18 disposed within the central opening 16. This field in turn generates a high intensity pulsed magnetic field within the field shaper which induces a current in the workpiece disposed within the field shaper. The workpiece is formed by the interaction of the high intensity magnetic field within the field shaper and the current induced in the workpiece. Clamping means 26 prevent the coil body from separating at the area of the slit 20 due to forces created by the field.

Referring now specifically to FIGURES 1 and 2 of the drawing, the slabs 12 and 14 of the coil body 10 are of a generally rectangular configuration and are preferably formed of a high strength conductive material such as beryllium copper, copper, etc. A plurality of bolts 28 extend through suitable holes provided in the slabs to secure the slabs to one another in tight-fitting face-to-face contact, each hole being countersunk at its opposite ends to receive the head or nut of the bolt. In addition, each slab is provided with a centrally located hole of circular cross sectional configuration, the hole of each slab being located so as to be co-axial with the hole of the other slab when the slabs are secured to one another. The holes thus combine to form the central opening 16 which is of such a diameter as to intimately receive the field shaping element 18, hereinafter described.

Since the coil body 10, in effect, serves as a secondary winding in relation to the primary winding 24, current is induced in the coil body when a current flows in the primary winding. If the coil body 10 were in the form of a closed loop, it would, in effect, become an electromagnetic shield and prevent the magnetic field from being established in the interior of the field shaper where the workpiece is supported. Accordingly, the slit or gap 20, previously referred to, is provided to break the continuity of the body and is defined by aligned cuts provided in the slabs 12 and 14. These cuts extend from the cylindrical surface of the central opening 16 to the lower edge of the coil body and are preferably filled with a non-compressive insulation 29 such as a thermosetting resin.

The flat slab 12 which comprises a portion of the coil body 10 has a substantially flat inner face 30 which is provided with a spiral groove 32 of generally semi-circular cross-sectional configuration. The axis of the spiral groove is generally co-linear with the axis of the central opening 16 and its inner end or origin is located adjacent the edge of the opening while its outer end or terminus is located adjacent the edge wall of the coil body. Similarly, the flat slab 14, which comprises the other half of the coil body 10, has a substantially flat inner face 34 adapted to be disposed in tight-fitting contact with the inner face 30 of the slab 12 and is provided with a spiral groove 36 which is the mirror image of the spiral groove 32 of the slab 12. When the two flat slabs 12 and 14 are secured together in face-to-face contact, the grooves 32 and 36 define the spiral bore 22 which lies generally in a single plane.

The bore 22 receives the primary winding 24 which, in the illustrated embodiment, is in the form of a spirally wound solid rod although a tubular rod might also be used, as when it is desired to convey a coolant through the winding. In either case, the rod is preferably fabricated of a conductive material such as copper, and the spiral winding of the rod is preferably such as to cause it to lie in substantially a single plane. A layer 38 of an appropriate high strength insulating material such as resin-impregnated glass fiber is placed around the primary winding to prevent electrical contact and sparking between the coil body 10 and the winding 24, as well as to impart strength thereto. One end of the primary winding 24, specifically the outermost end located adjacent the outer edge of the coil body, defines an input terminal 40 which is adapted to be connected to a suitable source 41 of high amperage current pulses, an example of such source being described in copending applications, Ser. No. 443,767, filed Mar. 17, 1965, as a continuation of Ser. No. 170,062, filed Jan. 31, 1962, and now Patent No. 3,247,440, and Ser. No. 397,971, filed Sept. 21, 1964, as a continuation-in-part of Ser. No. 311,427, filed Sept. 25, 1963.

In the illustrated embodiment, a source of energy such as a capacitor bank 42 is connected to the input terminal 40. A suitable switch 44 such as an ignitron or thyratron is connected between the capacitor bank 42 and the primary conductor 24 for selectively controlling the passage of current through the primary winding. The capacitor bank 42 is charged to a high voltage by a high voltage source 45 connected across it. In addition, a suitable switch 46 is connected in series between the capacitor bank 42 and the voltage source 45 to effect charging of the capacitor bank prior to the time when it is desired to supply a high amperage pulse of current.

The opposite end 47 of the primary winding or coil 24, specifically, the innermost end, is electrically connected to the coil body 10 adjacent the central opening 16. In addition, a grounded conductor 48 is connected to the coil body 10 at a terminal 49 and is also connected to the other side of the capacitor bank 42 through a conductor 50, thereby completing an electrical circuit. Thus, the coil body is maintained at ground potential so as to avoid any danger of accidental shocks if the coil body 10 is inadvertently touched.

As previously mentioned, the passage of a high intensity current through the primary winding 24 causes a very high density magnetic field to be established within the space defined by the central opening 16. This field is preferably shaped and concentrated either by the shape and configuration of the surface of the coil body defining the central opening 16 or, as in the illustrated embodiment, by the shape and configuration of the field shaper 18 which fits within the central opening and may be replaced to achieve various forming effects. The coil body 10 and the field shaper 18 together concentrate and shape this field.

The field shaper 18 of the illustrated embodiment includes an outer cylindrical surface having a diameter slightly less than that of the central opening 16, and having an inner surface which tapers inwardly from opposite ends of the element to define a central generally cylindrical throat 51 of reduced diameter which receives the workpiece. The field shaping element is formed of a pair of mating halves which are removable from the central opening and which permit the element to be assembled around an area of reduced cross section of a workpiece which is otherwise of a greater diameter than the throat 51. In addition, separation of the field shaping elements breaks the continuity thereof and permits a field concentration within the center of the element. Appropriate insulation 52 such as a thermosetting resin is disposed intermediate the mating halves of the field shaper 18. Similar insulation 52a is also disposed about the outer cylindrical surface of the field shaper 18, thereby insulating it from the coil body 10.

It should be apparent that during the pulsing of the coil 24 powerful forces are developed between the workpiece and the field shaper which tend to open or separate the coil body in the vicinity of the slit or gap 20 and thus place portions of the primary winding 24 in tension. To prevent the portions of the coil body from separating as a result of these forces, the clamping means 26 is provided and comprises a pair of horizontally disposed tie rods 53 which are formed of a durable material such as steel and which are positioned adjacent the lower portion of each of the outer faces of the coil body 10 and connected at their opposite ends to blocks 54 disposed flush with the ends of the body. Each of the rods 53 is threaded at its ends, which pass through suitable holes in the blocks and are retained therein by lock washers 55 and nuts 56. The blocks 54 are suitably insulated from the coil body 10 by a layer of insulation 57 and are maintained in tight contact with the coil body 10 by the tie rods 53.

In a preferred embodiment of the present invention the tie rods 53 are pre-stressed to provide a compressive force acting on the slit insulation 29 in excess of the anticipated peak expansive force on the slit generated by the magnetic pulse. This pre-stressing is accomplished by tightening the nuts 56 disposed at the opposite threaded ends of the tie rods. Consequently, the coil body will not spread at the slit until the compressive force across the slit is exceeded. No motion of the primary winding 24 occurs and it is not subjected to additional stresses.

Additional embodiments of the present invention which have been developed for providing various magnetic field concentrations are depicted in FIGURES 4 and 5. FIGURE 4 illustrates a coil body 58 having a central opening 60 which receives a field shaper 62 electrically insulated therefrom by a layer of insulation 63, and encloses an appropriately insulated primary winding 64 formed of a rod of substantially rectangular cross-sectional configuration. The walls of the central opening 60 are tapered so as to provide the opening with a smaller diameter adjacent one face of the coil body than adjacent the other. The outer surface of the field shaper is similarly tapered. The taper of these surfaces facilitates the insertion and removal of the field shaper from the coil body. Clamping means 66 prevents expansion of the coil body in the area of a slit or gap (not shown) similar to the slit 20 of the principal embodiment.

FIGURE 5 illustrates a coil assembly which includes a coil body 68 utilized in conjunction with a tapered field shaper 70 similar to that shown in FIGURE 4. A layer of electrical insulation 71 is disposed intermediate the adjacent surfaces of the coil body 68 and the field shaper 70. The coil body 68 encloses a coil 72 formed of a helically wound rod of rectangular cross-sectional configuration. Clamping means 74 are employed to prevent expansion of the coil body in the vicinity of a slit (not shown).

It should be understood that various modifications in the structural configuration of the embodiments previously described can be effected by one skilled in the art without deviating from the invention as set forth in the following claims.

We claim:

1. A coil assembly for use in an electromagnetic forming apparatus, said coil assembly comprising a discontinuous coil body formed of a conductive material and having an opening of sufficient size to accommodate a workpiece to be formed, said coil body including an internal bore of essentially flat spiral configuration commencing adjacent a surface of said opening and terminating adjacent an edge of the body, an elongated conductor disposed within said bore of said coil body and extending between the ends thereof, and means insulating the conductor from said coil body.

2. A coil assembly for use in an electromagnetic forming apparatus, said coil assembly comprising a discontinu-

ous coil body formed of a conductive material and having an opening therein of sufficient size to accommodate a workpiece to be formed, said coil body including an internal bore of essentially flat spiral configuration commencing adjacent a surface of said opening and terminating adjacent an edge of the body, an elongated conductor disposed within said bore of said coil body and extending between the ends thereof, said conductor being so proportioned relative to said bore so as to enable said coil body to provide support for each segment of said conductor and prevent movement thereof within said bore and means insulating the conductor from said coil body.

3. A coil assembly for use in an electromagnetic forming apparatus, said coil assembly comprising a discontinuous coil body having first and second mating portions formed of a conductive material and disposed in face-to-face relation, said coil body being provided with an opening therein substantially perpendicular to the adjacent faces of said first and second mating portions and adapted to establish a high density magnetic field therein when a high amperage current pulse is fed to said coil body, and being of sufficient size to accommodate a workpiece to be formed, each of the adjacent faces of said mating portions of said coil body being provided with a groove which cooperates with the groove of the adjacent face to define an essentially flat spiral bore commencing adjacent a surface of said opening and terminating adjacent an edge of the body, an elongated conductor disposed within said bore of said coil body and extending between the ends thereof, said conductor being so proportioned relative to said bore so as to enable said coil body to provide support for each segment of said conductor and prevent movement thereof within said bore and means insulating the conductor from said coil body.

4. A forming coil assembly for use in an electromagnetic forming apparatus, said assembly comprising a flat insulated coil of conductive material defining an axial opening and adapted to establish a high density magnetic field therein when a high amperage current pulse is passed therethrough, a coil body composed of conductive material having a generally cylindrical opening therein concentric with said axial opening and of sufficient size to accommodate a workpiece to be formed, said coil body being disposed about said insulated coil such that each portion on the circumference of said insulated coil is maintained in tight-fitting relationship with said coil body, said coil body being split from a surface of its central opening to a point on its circumference, and means for mechanically reinforcing said coil assembly so as to preclude expansion of said coil body at said split when the coil body is subjected to mechanical stress incident to the establishment of the field.

5. A forming coil assembly for use in an electromagnetic forming apparatus, said assembly comprising a flat insulated spiral coil of conductive material defining an axial opening and adapted to establish a high density magnetic field therein when a high amperage current pulse is passed therethrough, a coil body composed of conductive material having a generally cylindrical opening extending therethrough concentric with said axial opening and of sufficient size to accommodate a workpiece to be formed, said coil body being disposed about said insulated spiral coil such that each portion on the circumference of said spiral coil is maintained in tight-fitting relationship with said coil body, said coil body being split from a surface of its central opening to a point on its circumference, and clamp means for mechanically reinforcing said coil assembly so as to preclude expansion of said coil body at said split when the coil body is subjected to mechanical stress incident to the establishment of the field, said clamp means comprising a pair of blocks disposed at opposite ends of said coil body so that the surfaces of said coil body defining said split are in alignment with said blocks and means interconnecting said blocks and preventing movement thereof in a direction away from each other

incident to an applied force less than a predetermined force.

6. A forming coil assembly for use in an electromagnetic forming apparatus, said assembly comprising a flat insulated spiral coil of conductive material defining an axial opening and adapted to establish a high density magnetic field therein when a high amperage current pulse is passed therethrough, a coil body composed of conductive material having a generally cylindrical opening therein concentric with said axial opening and of sufficient size to accommodate a workpiece to be formed, said coil body being disposed about said insulated spiral coil such that each portion on the circumference of said spiral coil is maintained in tight-fitting relationship with said coil body, said coil body being split from a surface of its central opening to a point on its circumference, and clamp means for mechanically reinforcing said coil assembly so as to preclude expansion of said coil body at said split when the coil body is subjected to mechanical stress incident to the establishment of the field, said clamp means comprising a pair of blocks disposed at opposite ends of said coil body so that the surfaces of said coil body defining said split are in alignment with said blocks and tie rods for interconnecting said blocks and preventing movement thereof in a direction away from each other incident to an applied force less than a predetermined force.

7. A forming coil assembly for use in an electromagnetic forming apparatus, said assembly comprising a flat insulated spiral coil of conductive material defining an axial opening and adapted to establish a high density magnetic field therein when a high amperage current pulse is passed therethrough, a massive, high inertia coil body composed of conductive material having a generally cylindrical opening extending therethrough concentric with said axial opening and of sufficient size to accommodate a workpiece to be formed, said coil body being disposed about said insulated spiral coil such that each portion on the circumference of said spiral coil is maintained in tight-fitting relationship with said coil body, said coil body being split from a surface of its central opening to a point on its circumference, and clamp means for mechanically reinforcing said coil assembly so as to preclude expansion of said coil body at said split when the coil body is subjected to mechanical stress incident to the establishment of the field, said clamp means comprising a pair of blocks disposed at opposite ends of said coil body so that the surfaces of said coil body defining said split are in alignment with said blocks, and tie rods for interconnecting said blocks, said tie rods being subjected to a tensional force at least as great as the force applied by the magnetic field, thereby preventing movement of said blocks in a direction away from each other incident to an applied force less than the predetermined tensional force.

8. A forming coil assembly for use in an electromagnetic forming apparatus, said coil assembly comprising a coil body having first and second mating portions disposed in face-to-face relation, said coil body being provided with an opening extending therethrough substantially perpendicular to the adjacent faces of said first and second mating portions adapted to establish a high density magnetic field therein when a high amperage current pulse is passed therethrough, each of said mating portions being split from a surface of its central opening to a point on its circumference, said split being substantially completely filled with thermosetting resin insulation, each of the adjacent faces of said mating portions of said coil body being provided with a groove which cooperates with the groove of the adjacent face to define an essentially flat spiral bore commencing adjacent a surface of said opening and terminating adjacent an edge of the body, an elongated conductor disposed within said bore of said coil body and extending between the ends thereof, said conductor being so proportioned relative to said bore so as to enable said coil body to provide support for each

segment of said conductor and prevent movement thereof within said bore, means insulating the conductor from said coil body, a field shaping element of conductive material removably disposed within said opening in said coil body, said field shaping element having an aperture therein of sufficient size to accommodate a workpiece to be formed, and clamp means for mechanically reinforcing said coil assembly so as to preclude expansion of said coil body at said split when the coil body is subjected to mechanical stress incident to the establishment of the field said clamp means comprising a pair of blocks disposed at opposite ends of said coil body so that the surfaces of said coil body defining said split are in alignment with said blocks, and tie rods for interconnecting said blocks, said

tie rods being subjected to a tensional force at least as great as the force applied by the magnetic field thereby preventing movement of said blocks in a direction away from each other incident to an applied force less than the predetermined tensional force.

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