

United States Patent

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[56]

References Cited

UNITED STATES PATENTS

3,195,082	7/1965	Wetherill et al.	336/208
3,195,087	7/1965	Welch	336/208
2,509,713	5/1950	Achard	219/47
3,108,325	10/1963	Harvey et al.	18/16.5
3,258,573	6/1966	Morin et al.	219/9.5
3,372,566	3/1968	Schenk et al.	72/56
3,383,890	5/1968	Wildi	72/56

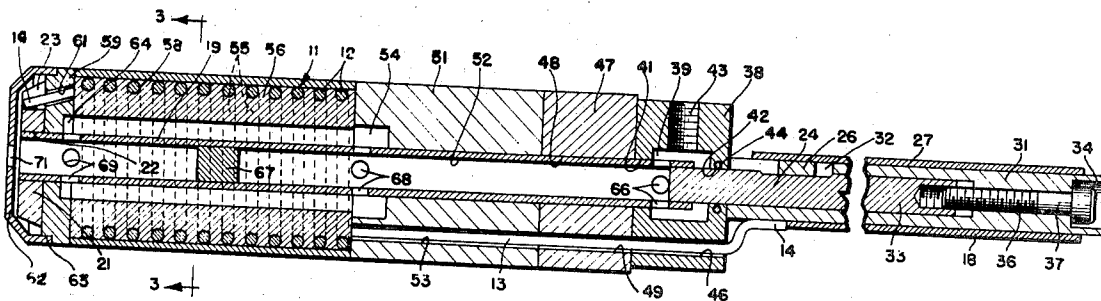
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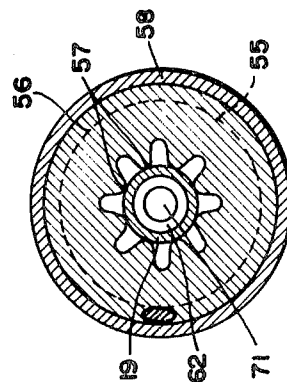
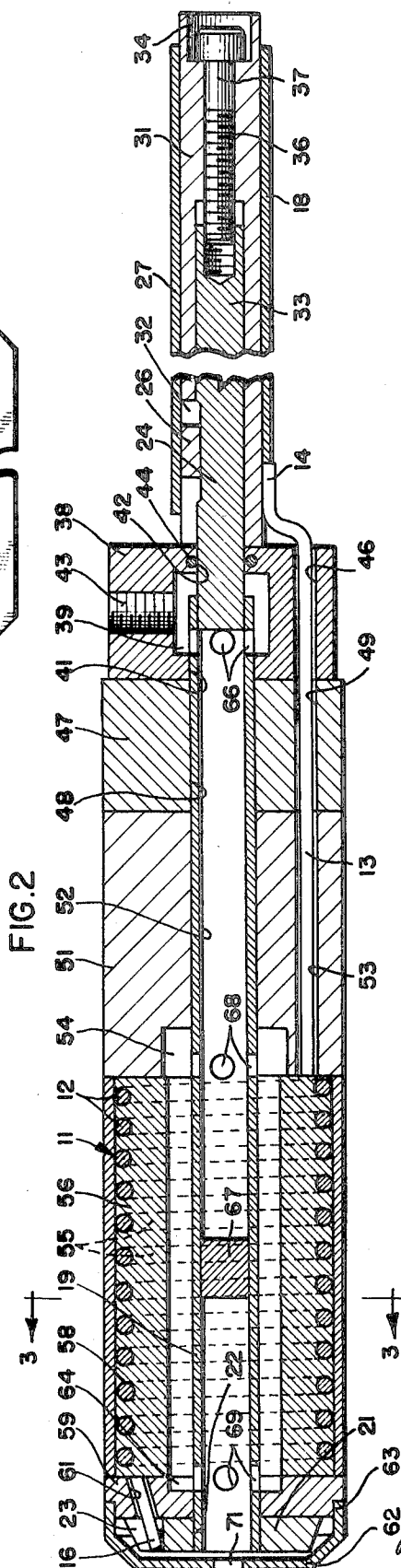
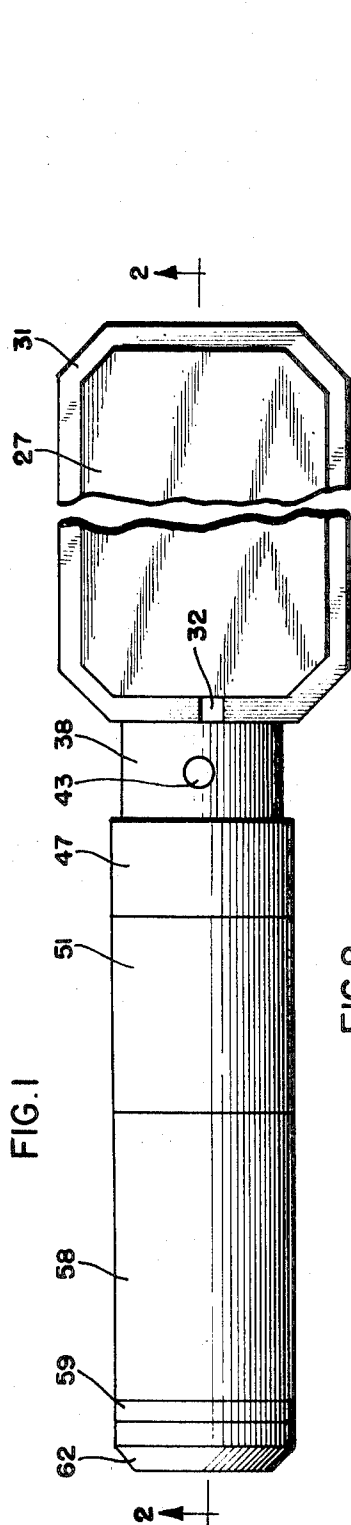
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[54] **ELECTROMAGNETIC FORMING ELEMENT**
7 Claims, 3 Drawing Figs.

[52] U.S. Cl. **72/56,**
29/421
[51] Int. Cl. **B21d 26/14**
[50] Field of Search. **72/56;**
29/421 N; 336/208

ABSTRACT: A forming element is described for use in magnetic forming apparatus. The forming element includes a conductor and a support member comprised of ceramic material. The support member, in addition to supporting the conductor, affords a vehicle for conducting heat from the conductor.





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ELECTROMAGNETIC FORMING ELEMENT

This invention relates to forming apparatus and, more particularly, to apparatus for forming material by energy acquired from a varying magnetic field.

Apparatus has been developed for forming materials by employing varying magnetic fields of high intensity. An example of such apparatus is shown and described in U.S. Pat. No. 2,976,907, issued Mar. 28, 1961, and assigned to the assignee of the present invention. In apparatus of this general type, an electric current pulse of high amperage is passed through a forming element comprising a conductor (e.g., in the form of a coil) to provide a desired magnetic field of high intensity. The current pulse may be applied to the conductor directly from a current pulse source or may be induced in the conductor by suitable inductive elements positioned adjacent thereto.

A conductive workpiece, positioned in the pulsed magnetic field produced by the conductor, has a current pulse induced in it. This current pulse interacts with the pulsed magnetic field to produce a force acting on the workpiece. If the force is sufficiently strong, a deformation of the workpiece results. The shape of the deformation is dependent upon the distribution in time and space of the magnetic field and the position of the workpiece relative to the field. Repeated pulses of current may be applied to or induced in the conductor, thus causing a series of deforming impulses to act upon the workpiece.

The conductors used in magnetic forming apparatus are subject to severe forces during forming of the workpiece. In order that a nonyielding reaction will be furnished to the mechanical forces associated with the high strength magnetic field, the conductor is supported against movement relative to the workpiece. In the case of a helical coil, such support may be furnished in the form of a cylindrical support member positioned within the helical conductor with its outer surface in contact therewith and coaxial therewith. In the case of a spiral conductor configuration, the support therefor may be furnished by a suitable planar support member positioned in contact with one side of the conductor perpendicularly of the axis thereof. In order to avoid current leakage, and hence a reduction in the efficiency of the forming apparatus, the support member utilized should have a high dielectric strength (i.e., high electrical resistance). Typical materials heretofore utilized as support members, such as composites of fiber glass, although having very high compression strength, have also exhibited a low modulus of elasticity, typically considerably lower than the material of the conductor itself. As a result, loading forces cause excessive compression thereof and a corresponding excessive strain on the conductor.

During operation of magnetic forming apparatus, repeated pulsing produces a considerable amount of heat in the conductor due to ohmic losses therein. If such heat is not adequately removed, structural damage to the conductor may result. In addition, a high operating temperature may cause a reduction in efficiency due to an increase in the resistance of the conductor to the passage of current therethrough. Accordingly, many conductors in magnetic forming apparatus have been made hollow and a cooling fluid has been circulated through the conductor itself. As a result, the number of possible coil designs has been somewhat limited due to the necessity for incorporating coolant flow passages in the conductor.

It is an object of this invention to provide improved magnetic forming apparatus.

Another object of the invention is to provide magnetic forming apparatus in which forces loading the conductor are transferred to a supporting member with a minimum strain on the conductor.

A further object of the invention is to provide magnetic forming apparatus in which cooling of the conductor is effected without utilizing coolant flow passages in the conductor.

Other objects of the invention will become apparent to those skilled in the art from the following description, taken in connection with the accompanying drawings wherein:

FIG. 1 is a top view of magnetic forming apparatus constructed in accordance with the invention;

FIG. 2 is an enlarged sectional view taken along the line 2-2 of FIG. 1; and

FIG. 3 is a sectional view taken along the line 3-3 of FIG. 2.

Very generally, the apparatus of the invention, as illustrated herein, comprises a conductor responsive to pulses of electrical energy applied thereto to conduct the current for producing a magnetic field for forming a workpiece disposed in the magnetic field. A support member supports the conductor and is comprised of ceramic material. The support member has a surface which is positioned with respect to surface of the conductor to conduct a substantial amount of heat from the conductor. Means are provided for removing heat from the support member to thereby cool the conductor.

Referring now particularly to FIGS. 1 to 3, the apparatus illustrated therein is for producing an expansion-type deformation in a workpiece which is positioned surrounding the conductor 11. The working part of the conductor 11 consists of a series of helical turns 12, the conductor in this region being of a generally circular cross section. The conductor 11 further includes a lead-in section 13 which extends from one end of the series of helical turns 12 generally parallel with the axis of the helix. The end of the lead-in section 13 opposite the helical turns 12 is provided with an s-shaped offset section 14 for reasons explained below. The opposite end of the series of helical turns 12 from the lead-in conductor 13 includes a return section 16 which extends generally axially and slightly inward from the end of the series of helical turns.

Although the cross section of the conductor 11 at the helical turn section is shown as being generally circular, other cross sections may be utilized. For example, the cross section of the conductor at the helical turns may be such as to be flat on one edge and round on the other in order to fill completely the cross section of the helical groove 55, described below. This shape may be achieved by machining after the conductor is wound, or may be achieved by extruding the conductor in the desired shape.

Current is supplied to the conductor 11 through a broad flat terminal plate 18. The offset section 14 of the lead in section 13 of the conductor is brazed to the plate 18. Suitable means, not illustrated, are connected to the terminal plate 18 for supplying current pulses thereto.

The current pulse, after passing through the conductor 11, is returned via a return conductor 19. The return conductor 19 consists of a tube located coaxial with the axis of the helical turns 12 of the conductor 11. The return conductor 19 is connected to the return section 16 of the conductor 11 by means of an end fitting 21 of conductive material. The fitting 21 is provided with a central opening 22 therein in which the tubular return conductor 19 is secured for electrical contact. The return section 16 of the conductor 11 extends into a slot 23 provided at an appropriate location in the outer periphery of the fitting 21, and is suitably secured to the fitting such as by brazing.

Current returning from the conductive 11 along the tubular return conductor 19 is passed from the return conductor on a coupling rod 24. The coupling rod 24 fits within one end of the return conductor 19 and is suitably secured thereto, such as by brazing. A block 26 of conductive material is suitably secured, such as by brazing, to the coupling rod 24. A return contact plate 27, attached to a suitable return circuit in the unillustrated pulse supplying means, is in electrical contact with the block 26, thereby completing the path for current return from the conductor 11.

The conductive plates 18 and 27 are secured, by suitable screws, not shown, to opposite sides of a slab 31 of insulating material. A slot 32 is provided in the slab 31 on the side to which the plate 27 is attached. The slot 32 accommodates the block 26 described above. The slab 31 is also provided with a central opening 33 therein for accommodating the coupling rod 24, the latter extending a substantial distance past the location of the block 26. A recess 34 is provided in one end of the slab 31 and a hole 36 communicates between the recess 34

and the opening 33. The hole 36 is aligned with the opening 33, and a bolt 37 is passed through the hole 36 and threaded into a suitable opening in the end of the coupling rod 24.

A base block 38 of generally cylindrical shape is positioned adjacent the edge of slab 31 opposite the recess 34. The base block 38 has a central cavity or plenum 39 therein which surrounds the juncture of the return conductor 19 and the coupling rod 24. An opening 41 is provided from the plenum 39 to the exterior of the base block 38 permitting the return conductor 19 to extend into the plenum 39. Similarly, an opening 42 is provided at the opposite side of the plenum 39 aligned with the opening 41 for allowing the coupling rod 24 to pass into the plenum 39. A threaded fluid inlet passage 43 is provided having an axis at right angles to the axis of the openings 41 and 42 for providing an inlet flow of fluid coolant under pressure. The opening 43 is threaded for accommodating suitable connecting means, not shown. An annular seal 44 is provided surrounding the opening 42 and engaging the periphery of the coupling rod 24. A further opening 46 is provided in the base block 38 parallel with the axis thereof and near the periphery thereof. The opening 46 allows the lead-in section 13 of the conductor 11 to pass through the base block.

A cylindrical spacer 47 is provided adjacent the base block 38. The spacer 47 has a central opening 48 therein, through which the return conductor 19 passes. Additionally, an opening 49 passes through the spacer 47 parallel with the opening 48 but adjacent the periphery of the spacer. The opening 49 is aligned with the opening 46 in the base block 38 and permits the lead-in section 13 of the conductor 11 to pass therethrough.

A manifold spacer 51 is positioned adjacent the spacer 47 and has a central opening 52 therein through which the return conductor 19 passes. A further opening 53 is provided in the manifold spacer 51 adjacent the periphery thereof and parallel with the opening 52. The opening 53 is aligned with the opening 49 in the spacer 47 and allows the lead-in section 13 to pass therethrough. A recess 54 is provided in the end of the manifold spacer 51 adjacent the helical turns 12 of the conductor 11 and, as will be explained, forms a manifold or plenum for fluid coolant.

The conductor 11 is supported internally, in the region of the helical turns 12, by a support member 56. The support member is provided with a helical groove 55 in its surface to accommodate the helical turns 12. The outer surface of the support member is cylindrical and is provided with a helical groove in which the helical turns 12 are disposed. As may be seen in FIG. 3, the support member is hollow for accommodating the return conductor 19 and includes a plurality of inwardly extending fins 57 for the purpose of providing a large surface for heat transfer purposes. An outer sleeve 58 covers the helical turns 12 and the support member 56 and is made of insulating material. The outer diameter of the support member 56 is less than the outer diameter of the manifold spacers 51 and therefore the latter element provides a shoulder against which the sleeve 58 abuts. The sleeve is retained in this position by an end washer 59 which is against the end of the support member 56 and which is held in position by the end fitting 21 soldered to the return conductor 19. The end washer 59 is provided with a passage 61 therein through which the return segment 16 of the conductor passes. An end cap 62 of insulating material fits into a shoulder 63 on the end washer 59. The end washer 59, the cap 62, and the sleeve 58, all being of insulating material, as well as the spacers 51 and 47 and the base block 38, form an insulative protective coating for the exterior of the coil assembly. A recess or plenum 64 is provided in the washer 59 adjacent the hollow interior of the support member 56 for reasons which will be explained below.

During operation of the apparatus, the conductor 11 is subject to high forces acting radially inward at the region of the helical turns 12. In order to resist such forces with a minimum strain of the conductor, the support member 56 is comprised of a dense ceramic material which exhibits good

electrical insulating properties and a very high compression strength and a high modulus of elasticity. It is also desirable that the support member exhibit an exceptionally high thermal conductivity. Aluminum oxide (Al_2O_3) has been found to be of particular advantage for use in this connection. Deformation of the metallic conductor 11 during operation of the apparatus is minimized, the conductor loading being transferred to the ceramic support member with minimum strain of the conductor.

During magnetic forming operations which require repeated and rapid pulsing of current through the conductor, the conductor may heat up due to ohmic losses therein. The configuration of the apparatus illustrated in FIGS. 1 to 3, and the particular material of which the support member is constructed, enables efficient cooling of the conductor to be accomplished without the necessity of providing coolant passages within the conductor itself. To this end, a fluid coolant is introduced to the plenum 39 under pressure through the passage 43. A plurality of holes 66 are provided in the return conductor 19 communicating between the interior thereof and the plenum 39. Accordingly, the fluid coolant is forced from the plenum into the interior of the return conductor 19. The return conductor is plugged, at an axial position lying between the plenum 54 and the plenum 64, by a plug 67. A plurality of holes 68 communicate between the interior of the return conductor and the plenum 54. Due to the position of the plug 67, the fluid coolant is expelled through the holes 68 into the plenum 54. The coolant then passes along the hollow interior of the support member 56, removing heat therefrom due to the large area of heat exchange provided by the fin construction.

After passing through the hollow finned interior of the support member, the fluid coolant passes into the plenum 64 and, from there, through a plurality of openings 69 back into the interior of the return conductor 19, but on the opposite side of the plug 67 from the openings 68. An opening 71 is provided in the end cap 62 and the fluid coolant is expelled therethrough from the return conductor 19.

Because of the high compression strength and the high modulus of elasticity of the ceramic material of the support member 56, good support is given to the conductor 11 against the forming forces such that strain on the conductor is minimized. Moreover, because the thermal conductivity of the ceramic material is relatively high, heat is adequately removed from the conductor by the coolant flowing through the hollow finned interior of the support member.

It may therefore be seen that the invention provides improved magnetic forming apparatus in which satisfactory support for the conductor of the apparatus is provided but in which minimum strain is exerted on the conductor during high current periods. Moreover, satisfactory heat removal from the conductor is possible without the necessity of providing for coolant passages within the conductor itself.

Various modifications of the invention, in addition to those shown and described herein, will become apparent to those skilled in the art from the foregoing description and accompanying drawings. Such modifications are intended to fall within the scope of the appended claims.

What I claim is:

1. A forming element for use in magnetic forming apparatus, comprising, a conductor having a plurality of helical turns and being responsive to pulses of electrical energy applied thereto for conducting a current producing a magnetic field for forming a workpiece disposed in the magnetic field and surrounding the helical conductor, and a support member for supporting said conductor against forces directed radially inward during forming, said support member being comprised of a tubular unitary body of solid dense ceramic material coaxial with and within the turns of said conductor and in direct contact therewith, and means within said tubular support member for removing sufficient heat from said support member to cool said conductor.

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2. A forming element according to claim 1 further including a return conductor comprising an elongated member disposed centrally of said support member for providing a return current path from said conductor.

3. A forming element according to claim 1 wherein said heat removing means include means for passing a fluid coolant proximate a further surface of said ceramic member.

4. A forming element according to claim 3 wherein said fluid coolant contacts said further surface.

5. A forming element according to claim 4 wherein said further surface is finned.

6. A forming element according to claim 1 wherein the ceramic material of which said support member is comprised consists of aluminum oxide.

7. A forming element according to claim 2 wherein said elongated member is hollow and provides a passage for the flow of fluid coolant for cooling said conductor.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,599,461 Dated August 17, 1971

Inventor(s) Jaromir Astl

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 1, line 29 - for "severs", read "severe".

Column 1, line 49 - after "forces", insert "transmitted by the
conductor to the support member may".

Column 2, line 12 - for "to surface", read "to a surface".

Column 2, line 57 - after "conductive", insert "coil".

Column 3, line 57 - for "its", read "fits".

Column 5, line 4 - for "form", read "from".

Signed and sealed this 7th day of March 1972.

(SEAL)

Attest:

EDWARD M. FLETCHER, JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents