May 31, 1966 J. H. MALMBERG 3,253,443

FORMING DEVICE

Original Filed Feb. 18, 1963

Fig. 1

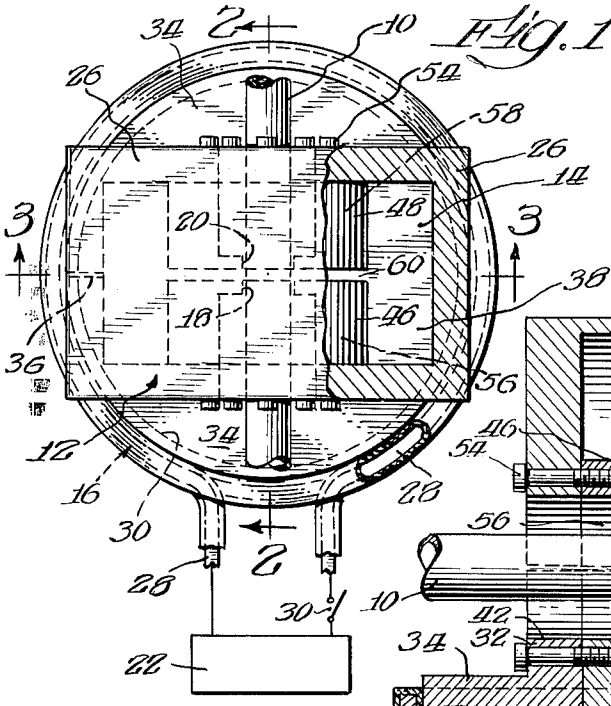


Fig. 2

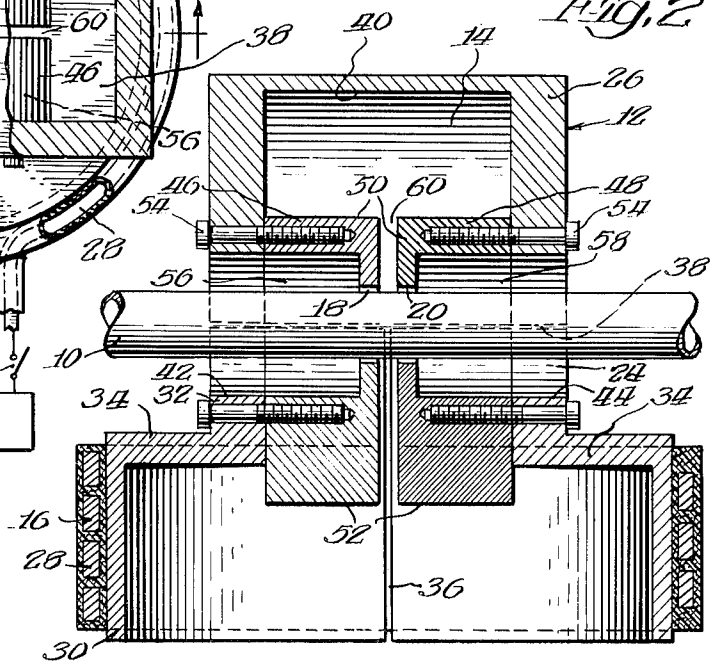
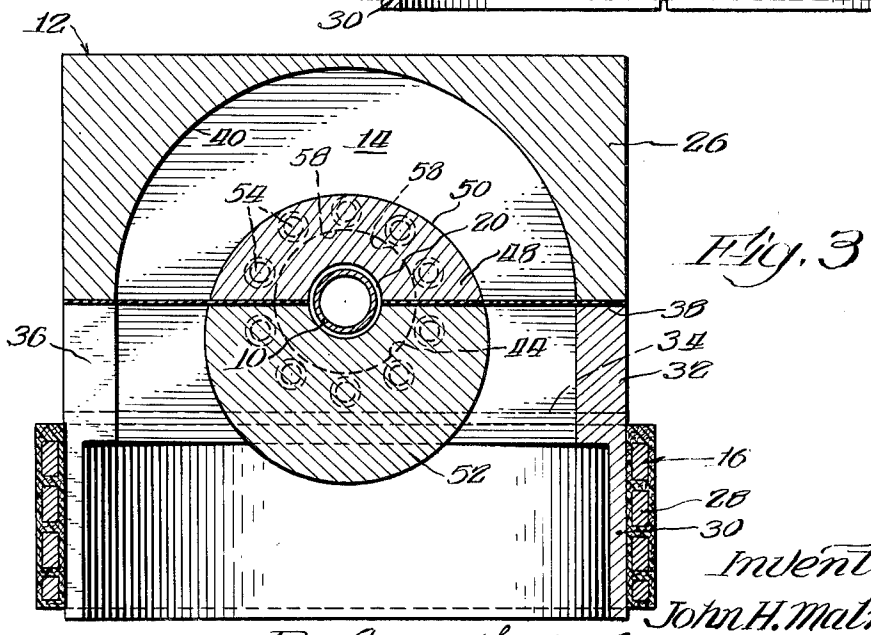


Fig. 3



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United States Patent Office 3,253,443 Patented May 31, 1966

3,253,443

FORMING DEVICE

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Continuation of application Ser. No. 259,108, Feb. 18, 1963. This application Mar. 4, 1965, Ser. No. 440,353
6 Claims. (Cl. 72—56)

This is a continuation of application Serial No. 259,108, filed February 18, 1963, now abandoned.

The present invention relates to forming apparatus and method and particularly to a method of forming a work piece and to a forming coil assembly for an electromagnetic forming apparatus.

In recent years, methods and apparatus have been developed for forming materials by employing magnetic fields of high flux density. In such apparatus, a magnetic field of high flux density is set up about a shaped conductor by passing a current pulse of high amperage through the conductor. This high density, pulsed magnetic field induces a current in a conductive work piece disposed in the magnetic field, which current is concentrated on the surface of the work piece. This induced current is always in such a direction as to tend to exclude the magnetic field from the work piece. This results in pressure being applied to the work piece which is equal to the energy density of the magnetic field. This pressure is made sufficiently high to form the work piece.

Normally, in such electromagnetic forming equipment, the cross section of a work piece, such as an elongated tube, has been reduced by concentrically disposing a coil or a tubular flux shaping element about the work piece. The work piece has been inserted into the coil and removed therefrom by moving it longitudinally. In certain applications it is inconvenient and/or impossible to insert and remove the work piece by moving it longitudinally. This is especially true when the work piece is of considerable length or when the work piece has flanged ends.

An object of the present invention is the provision of a method of forming a work piece and apparatus therefor. Another object is the provision of a forming coil assembly for an electromagnetic forming apparatus, which assembly may be quickly and easily disposed upon and removed from a work piece. Still another object of the invention is the provision of a forming coil assembly for an electromagnetic forming apparatus, which assembly may be adapted to form diverse sizes of work pieces. A further object is the provision of a forming coil assembly for an electromagnetic forming apparatus, which coil assembly may be removed from the work piece without disconnecting any electrical contacts. Still a further object is the provision of an electromagnetic forming coil assembly which is efficient in operation, relatively inexpensive to manufacture, and durable in use.

Other objects and advantages of the present invention will become apparent by reference to the following description and acompanying drawings.

In the drawings:

FIGURE 1 is a plan view of an electromagnetic coil assembly employing various features of the present invention, portions of the coil assembly being broken away to better illustrate certain parts thereof.

FIGURE 2 is an enlarged cross sectional view taken generally along line 2—2 of FIGURE 1, and

FIGURE 3 is an enlarged cross sectional view taken generally along lines 3—3 of FIGURE 1.

Generally in accordance with the present invention, a method of forming a metallic work piece includes applying at least one current pulse through a coil whereby said coil serves as a source of magnetomotive force. The flux produced by the magnetomotive force is guided to the work piece disposed exteriorly of the coil, whereat the flux is concentrated to thereby form the work piece.

For purposes of explanation, the method is described hereinafter with respect to a forming coil assembly for carrying out the method. In general, the forming coil assembly shown in the drawing is adapted to reduce the diameter of an elongated, tubular workpiece **10** in two places. Generally, the illustrated forming coil assembly includes a conductive means **12** defining an elongated passageway or cavity **14** which is closed at one end, and an insulated coil **16** of conductive material which is disposed about the conductive means **12** adjacent the mouth of the cavity **14**. The conductive means **12** is provided with a pair of opposed apertures **18** and **20** which serve as work spaces. The workpiece **10** is supported in the apertures **18** and **20** in spaced relation thereto, whereby, when the coil **16** is connected to a source **22** of current pulses, the flux generated by the coil **16** is guided by the cavity **14** to the work spaces. The flux escapes from the cavity **14** through the spaces between the walls of the apertures **18** and **20** and the adjoining portions of the workpiece **10**, resulting in magnetic pressure being applied to the portions. The conductive means **12** is split into two sections **24** and **26** at the work spaces **18** and **20** so that the workpiece **10** may be positioned in and removed from the work spaces **18** and **20** by removing one of the sections of the conductive means **12**.

More specifically, in the illustrated embodiment, the forming coil assembly includes the coil **16** which is formed of a suitably insulated conductor **28**. The conductor **28** is connected through a switch means **29**, such as an Ignitron **29**, to the source **22** of high amperage pulses, such as a charged capacitor bank. When the coil **16** is connected to the source **22**, the coil **16** serves as a source of magnetomotive force.

The magnetic flux produced by the magnetomotive force is guided to the work spaces **18** and **20** by the conductive means **12** which defines the cavity or passageway **14**. For purposes of explanation, the coil assembly is described hereinafter as it is orientated in FIGURES 2 and 3. However, it should be understood that the coil assembly may be operated in any convenient orientation.

The illustrated conductive means **12** is divided horizontally into the upper and lower sections **26** and **24**, respectively, for purposes hereinafter described. The sections are clamped together by a suitable means (not shown) such as an insulated parallel clamp, etc. The lower section **24** includes a vertically extending, generally tubular lower portion **30**, and a hollow generally rectangular upper portion **32** which is integrally connected to the tubular lower portion **30** by a horizontally extending, intermediate wall **34**.

As shown in the drawings, the coil **16** is disposed on the tubular lower portion **30**. The lower section **24** is provided with a vertically extending slit **36** so that the section **24** does not act as a shorted turn around the flux. The upper section **26** is insulated from the lower section **24** by a thin sheet **38** of insulating material in order to completely break electrical contact between the sections. The sheet **38** is made as thin as possible to minimize flux leakage outwardly through the space between the sections **24** and **26**.

The upper section **26** is generally rectangular in shape and its outer dimensions are made the same as the upper rectangular portion **32** of the lower section **24**. The upper section **26** is provided with a semicylindrical recess **40** which has a horizontal cross section corresponding to that of the hollow cavity in the rectangular upper portion **32** of the lower section **24**.

As shown particularly in FIGURE 2, the elongated tubular, conductive workpiece **10**, which is to be swaged,

is received in horizontally aligned, generally cylindrical outer apertures 42 and 44 defined in the longer walls of the conductive means 12. One half of each of the outer apertures 42 and 44 is formed in the upper section 26 and one half is formed in the upper portion 32 of the lower section 24. The outer apertures 42 and 44 are of a much greater diameter than the workpiece 10 to thereby make the annular area between the workpiece and the apertures 42 and 44 much greater than the annular area of the work spaces between the workpieces and the apertures 18 and 20. Thus, swaging does not take place at these outer apertures 42 and 44. The workpiece 10 is normally insulated and is suported centrally within the outer apertures 42 and 44 by a suitable means (not shown).

In the disclosed embodiment, the tubular workpiece 10 is swaged so as to be reduced in diameter at two longitudinally spaced locations intermediate the outer apertures 42 and 44. The swaging is afforded at two horizontally spaced and aligned inner apertures 18 and 20 which receive the workpiece 10 and serve as work spaces. The inner apertures 18 and 20 are defined by a pair of horizontally spaced, cylindrical split dies 46 and 48 of conductive material such as copper, beryllium copper, etc.

Each of the illustrated dies 46 and 48 includes an upper and a lower jaw, 50 and 52, respectively. Each upper jaw 50 is suitably fastened, as by screws 54, to the inner surface of the long wall of the upper sections 26, and each lower jaw 52 is similarly fastened to the upper portion 32 of the lower section 24. In order to limit the width of the swaging in the tubular workpiece 10, the dies 46 and 48 are provided with horizontally extending cylindrical recesses 56 and 58, respectively, which are larger in diameter than the inner apertures 18 and 20. Preferably, the recesses 56 and 58 correspond in diameter to the outer apertures 42 and 44 and are aligned with the same.

The diameter of each of the inner apertures 18 and 20 is made only slightly larger than the diameter of the workpiece 10 so that the flux passing or escaping through the annular spaces therebetween is concentrated or increased in density. This increased density flux increases the magnetic pressure on the workpiece and is made strong enough to exceed the yield strength of the workpiece 10, thereby reducing the diameter of the workpiece 10.

Since the lower portions of annular spaces between the walls of the inner apertures 18 and 20 and the workpiece 10 are closer to the source of magnetomotive force, (i.e., the coil 16) the flux will, unless compensations are made for the same, be more dense at these lower portions. In the illustrated embodiment the asymmetrics in the magnetic field at these annular spaces are reduced to substantially zero by increasing the reluctance of the path of the magnetic field to the lower portion of the annular spaces. In this connection, the lower portion of a vertical gap 60 between the dies 46 and 48 is increased in length by downwardly offsetting the center of the outer radius of the dies 46 and 48 with respect to the center of the inner apertures 18 and 20. If a certain amount of asymmetrics is desired in the magnetic field, the amount of offset may be reduced.

In operation, the workpiece to be formed is suitably supported in spaced relation to the lower jaw members 52 of the dies 46 and 48. The upper cavity-forming section 26 is then lowered in position on top of the lower cavity-forming section 24 and is suitably clamped thereto. The coil 16 is then connected to the source 22 of current pulses by closing the switch means 29, whereby a magnetic flux is set up about the coil 16 which is forced into the cavity 14. The flux passes through the vertical gap 60 between the dies 46 and 48 and escapes through the annular spaces surrounding the workpiece 10. The resulting magnetic pressure swages the workpiece at two locations. The top cavity-forming section 26 may then be lifted and the workpiece 10 removed without moving the lower cavity-forming section 24.

As previously indicated, the workpiece in the above described embodiment is swaged in two places. However, if only one swaged area is desired, it may be obtained by replacing one of the dies with one having an aperture which is greater in length and diameter thereby spreading the force of the magnetic flux over a larger area so that the yield strength of the workpiece is not exceeded. Also, the upper portion 32 of the lower cavity-forming section 24 may be removably connected to the lower tubular portion 30 so that various diverse shapes and sizes of upper portions may be employed with the same coil 16. Moreover, the dies may be changed, and while in the illustrated embodiment a tubular workpiece is formed, it should be understood that other shapes of workpieces may be formed and different operations performed by changing the shape of the work spaces. In addition, the upper cavity-forming section may be replaced by a cavity-forming section similar to the described lower cavity-forming section.

Various other changes and modifications may be made in the above described forming coil assembly or method without departing from the spirit or scope of this invention.

Various features of the present invention are set forth in the accompanying claims.

What is claimed is:

1. Apparatus for forming a conductive workpiece, comprising a coil defining a space, means for coupling said coil to a source of current pulses, whereby said coil serves as a source of magnetomotive force, a conductive means defining an elongated passageway, and a work space at one end of said conductive means for receiving a conductive workpiece, said work space being at a location which is spatially removed from the space defined by said coil, said coil being disposed adjacent the other end of said passageway whereby said conductive means guides flux produced by said magnetomotive force into a predetermined configuration at the surface of the workpiece positioned in said work space.

2. Apparatus for forming a conductive workpiece, comprising a coil defining a space, means for coupling said coil to a source of current pulses, whereby said coil serves as a source of magnetomotive force, and a conductive means defining an elongated passageway, the walls of said conductive means being provided with a pair of aligned apertures which extend through said conductive means at a location which is spatially removed from the space defined by said coil, thereby affording a work space for a workpiece, said coil being disposed adjacent one end of said passageway whereby said conductive means guides flux produced by said magnetomotive force into a predetermined configuration at the surface of the workpiece positioned in said work space.

3. Apparatus for forming a conductive workpiece, comprising a coil defining a space, means for coupling said coil to a source of current pulses, whereby said coil serves as a source of magnetomotive force, a conductive means defining an elongated passageway, said conductive means including two sections which meet in a plane which is spatially removed from the space defined by said coil, a thin sheet of insulation between said sections, the walls of said conductive means being provided with a pair of aligned apertures which extend through said conductive means at said plane, thereby affording a work space for a workpiece, said coil being disposed adjacent one end of said passageway whereby said conductive means guides flux produced by said magnetomotive force into a predetermined configuration at the surface of the workpiece positioned in said work space.

4. Apparatus for forming a conductive workpiece, comprising a coil defining a space, means for coupling said coil to a source of current pulses, whereby said coil

serves as a source of magnetomotive force, and a conductive means defining an elongated passageway closed at one end, said conductive means including two sections which meet in a plane which is spatially removed from the space defined by said coil, a thin sheet of insulation between said sections, walls of said conductive means being provided with a pair of aligned apertures which extend through said conductive means at said plane, thereby affording a work space for a workpiece, said coil being disposed adjacent the open end of said passageway whereby said conductive means guides flux produced by said magnetomotive force into a predetermined configuration at the surface of the workpiece positioned in said work space.

5. Apparatus for forming a conductive workpiece, comprising a coil defining a space, means for coupling said coil to a source of current pulses, whereby said coil serves as a source of magnetomotive force, and a conductive means defining an elongated passageway closed at one end, said conductive means including two sections which meet in a plane which is spatially removed from the space defined by said coil, a thin sheet of insulation between said sections, the walls of said conductive means being provided with a pair of aligned apertures which extend through said conductive means at said plane, a pair of spaced dies disposed in the passageway adjacent said apertures, one of said dies being connected to the conductive means adjacent one aperture therein, and the other die being connected to the conductive means adjacent the other aperture, said dies being split to meet in the meeting plane of said sections, each of said dies being provided with an aperture which serves as a work space for receiving the workpiece to be formed, which aperture is smaller in diameter than the first mentioned apertures in the conductive means, said coil being disposed adjacent the open end of said passageway whereby said conductive means guides flux produced by said magnetomotive force into a predetermined configuration at the surface of the workpiece positioned in said work space.

6. Apparatus for forming a conductive tubular workpiece, comprising an insulated coil defining a space, means

for coupling said coil to a source of current pulses, whereby said coil serves as a source of magnetomotive force, a conductive means defining a cavity, said conductive means including a tubular portion and a hollow rectangular portion joined at one end to the tubular portion, the other end of said rectangular portion being closed, said coil being disposed on said tubular portion, said rectangular portion including two sections which meet in a plane which is spatially removed from the space defined by said coil, a thin sheet of insulation between said sections, said rectangular portion being provided with a pair of aligned apertures in opposite walls thereof, part of each aperture being in one of said sections and the other part of each aperture being in the other of said sections, a pair of spaced dies disposed in the cavity adjacent said apertures, one of said dies being connected to the rectangular portion adjacent one aperture therein, and the other die being connected to the rectangular portion adjacent the other aperture, said dies being split to meet in the meeting plane of said sections, each of said dies being provided with an aperture for receiving the workpiece to be formed, which aperture is smaller in diameter than the apertures in said rectangular portion, the length and width of the spacing between said dies being adjusted so that field is substantially symmetric at the apertures in the dies.

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