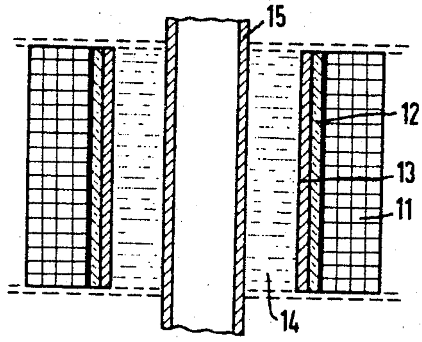

Fig. 1

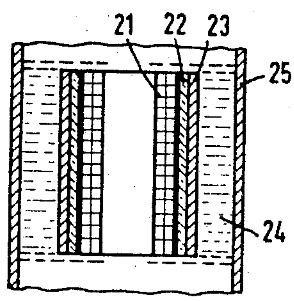

Fig. 3

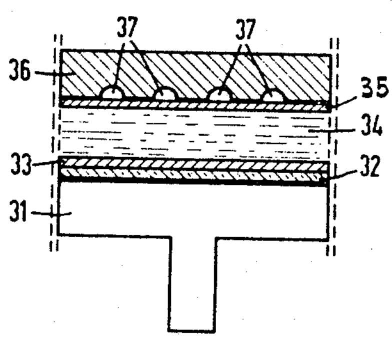

Fig. 5

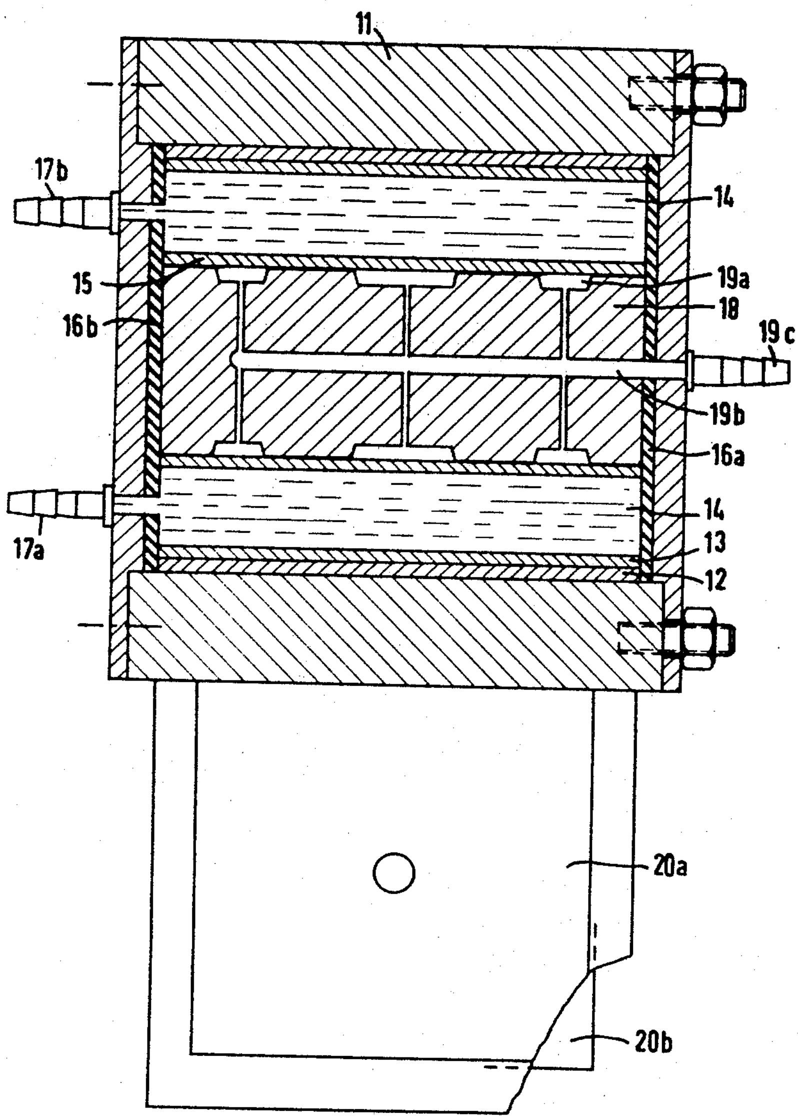

Fig. 2

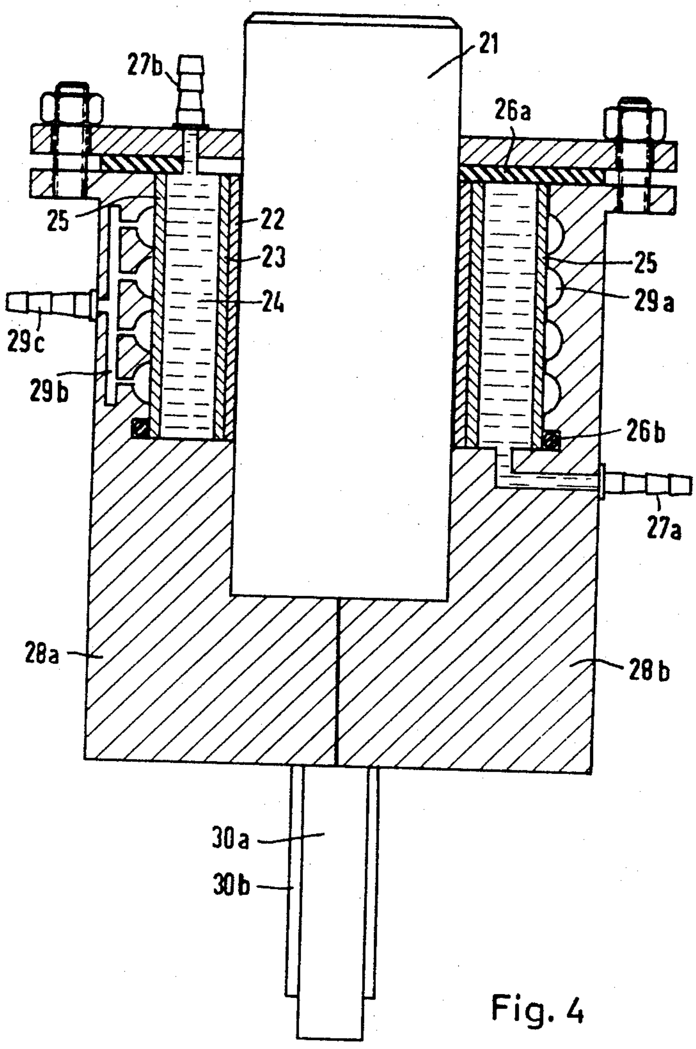

Fig. 4

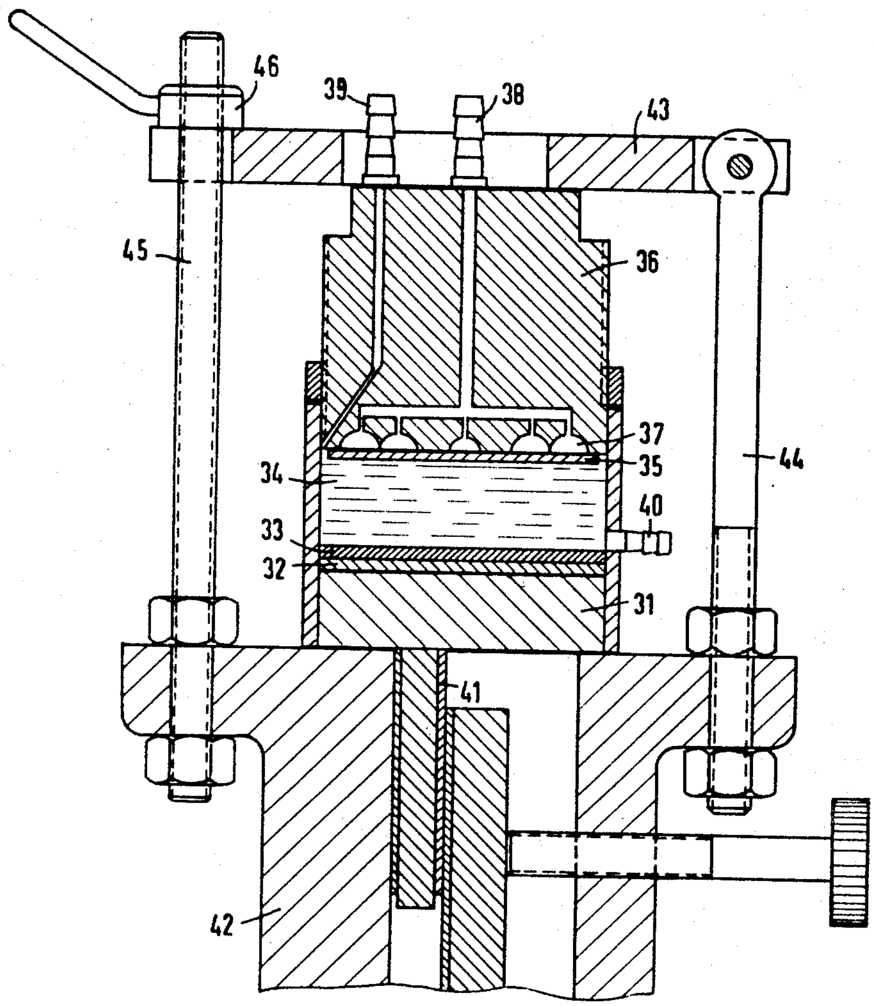

Fig. 6

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3,447,350

METHOD AND DEVICE FOR THE MAGNETIC FORMING OF METALLIC WORKPIECES

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Continuation of application Ser. No. 462,280, June 8, 1965. This application Feb. 5, 1968, Ser. No. 703,186
Claims priority, application Germany, June 10, 1964, S 91,449
Int. Cl. B21d *26/14;* B21j *5/04*
U.S. Cl. 72—56 4 Claims

ABSTRACT OF THE DISCLOSURE

Apparatus for forming metallic workpieces with pulsed magnetic fields produced by work coils including a mechanically stable member and member of high electrical conductivity in juxtaposition to the work coil and an incompressible fluid medium between the stable member and the workpiece, thereby producing by the coil magnetic field a shock wave through the two members and fluid medium to exert forming pressure upon the workpiece.

This application is a continuation of Ser. No. 462,280, filed June 8, 1965 and now abandoned.

My invention relates to methods and means for the direct forming of metallic workpieces with the aid of pulsed magnetic fields. This method, often called "Magneform" method, involves discharging capacitors through a work coil within extremely short periods of time, for example microseconds, to produce high-intensity magnetic fields which subject the workpiece to forming pressure. The attainable degree or formation for a given energy of the shock-current capacitors depends upon the electrical conductivity of the workpiece and upon the distance of the workpiece from the coil.

With a poor electrical conductivity of the workpiece, it has been heretofore necessary to place between coil and workpiece a driver sheet of copper or aluminum which transmits the resulting mechanical pressure upon the workpiece.

These known methods, however, have the disadvantage that the spacing between work coil and driver sheet varies, so that a reduction in pressure occurs as a consequence of an increase in spacing prior to attainment of the maximal discharge current from the capacitors.

Also known is a method which utilizes pressure waves for the forming of workpieces, the pressure waves issuing from an arc ignited in water which transmits them to the workpiece (Hydrospark process). If the shape of the work to be produced is not accurately rotationally symmetrical, it is generally necessary to employ an arc-igniting wire between the art electrodes. For some purposes, particularly for deep-draining of a workpiece, the ignition wire must be given the shape of a planar spiral. Due to the necessity of mounting the ignition wires between the electrodes to be submerged in water, the required setting-up periods are undesirably long with this type of forming method.

It is an object of my invention to provide a method of forming metallic workpieces with the aid of high-intensity pulsed magnetic fields which largely eliminates the above-mentioned shortcomings or disadvantages.

Another, more specific object of my invention is to provide a method of forming metallic workpieces with pulsed magnetic fields using a driver member between work coil and workpiece, which avoids the occurrence of an appreciable, if any, increase in spacing prior to attainment of the capacitor maximal discharge current.

Another object of the invention is to afford the shaping or otherwise forming of workpieces whose electrical conductivity is relatively low, without necessitating the use of driver sheets of the type heretofore employed for such purposes.

Still another object of the invention is to permit the forming of workpieces having greatly different external dimensions without the necessity of using field concentrators.

It is also among the objects of my invention to improve the pulsed magnetic-forming method by providing for better uniformity with respect to the distribution of the pressure exerted upon the workpiece and/or by increasing the efficiency of the process.

According to my invention, a mechanically stable solid medium of high electrical conductivity is placed in juxtaposition to the work coil, and an incompressible fluid medium is placed between the solid medium and the workpiece. Then a shock wave is produced by the coil magnetic field and through the solid medium and the fluid medium to impose the forming pressure upon the workpiece. The term "high electrical conductivity" is herein understood to refer to an electrical conductivity at least equal to that of electrolyte copper.

According to another feature of the invention, the method is preferably performed by employing, as the mechanically stable solid medium, a sheet structure composed of inter-bonded layers or strata which consist of the high-conductivity metal and of reinforcing metal respectively, the former metal being preferably electrolyte copper and the reinforcement metal being preferably steel.

For example, the mechanically stable medium of high electrical conductivity may consist substantially of a tube formed of electrolyte copper which is internally reinforced by a tube of steel, or the reinforcing tube of steel may be located on the outer surface of the copper tube. The mechanically stable medium may also consist of a substantially planar bimetallic sheet analogously composed of electrolyte copper and steel, for example. The incompressible fluid medium is preferably water, although other liquids such as mineral oil are likewise applicable.

The steel-reinforced sheet or tube of electrolyte copper is located directly adjacent to the work coil. On account of the high electrical conductivity, the pressure exerted upon the copper is relatively high and so is the energy of the resulting shock wave. The distance between the work coil and the copper member remains substantially constant, in contrast to the known "Magneform" process. Consequently no pressure reduction occurs because of any increase in spacing before the maximal discharge current is attained.

The invention will be further described with reference to embodiments illustrated by way of example on the accompanying drawings in which:

FIG. 1 shows schematically a method and device according to the invention for comprising a tubular workpiece, and FIG. 2 shows the same device more in detail.

FIG. 3 shows schematically and in section the essential parts of a device according to the invention for widening the tubular workpiece; and FIG. 4 shows in section the same device more in detail.

FIG. 5 shows schematically and in section the essential parts of a device for deep drawing a planar workpiece according to the invention; and FIG. 6 shows in section the same device more in detail.

Denoted by **11** in FIGS. 1 and 2 is a work coil, in this case a compression coil, to be energized by electric shock discharges from a battery of capacitors. The interior surface of the hollow-cylindrical coil is lined with a cylinder or tube **12** of electrolyte copper which is reinforced by a tube **13** of steel. The inner diameter of the bimetal member **12, 13** is considerably larger than the diameter of the tubular workpiece **15** to be formed so that when the workpiece is coaxially positioned, there remains an enclosed interspace **14** of annular shape which is completely filled with incompressible fluid medium, preferably water. Each field pulse subjects the internally steel-reinforced tube **12** of copper, being in immediate proximity to the work coil **11**, to an extremely high pressure which is propagated through the water as a shock wave onto the workpiece **15** where it causes the free deformation of the workpiece by compression.

In the example shown in FIG. 2, the interspace **14** is tightly enclosed with the aid of rubber seals **16***a* and **16***b* and is provided with inlet and outlet nipples **17***a*, **17***b* through which the water is supplied into the space or subsequently discharged therefrom. The workpiece **15** is seated on a subdivided mandrel **18** which, in this particular example, is shown to have a number of recesses **19***a* distributed over its periphery, in accordance with the particular shape to be imparted to the workpiece **15**. The recesses **19***a* communicate with a bore **19***b* terminating in a nipple **19***c* for connection to a vacuum pump. Prior to passing a capacitor discharge through the compression coil **11**, the recesses **19***a* are evacuated. The current is supplied to the respective ends of the coil through terminal straps **20***a* and **20***b*.

When the compression coil **11** is energized by the shock current, the resulting pressure wave deforms the workpiece **15** by forcing it into the depressions or recesses **19***a* of the mandrel **18**. By virtue of the subdivision of the mandrel **18**, it can thereafter be separated into individual parts and thus be removed from the interior of the workpiece.

FIG. 3 indicates how the method according to the invention may be applied for widening a tubular workpiece of steel. Denoted by **21** is the work coil (expansion coil). The coil is closely and tightly surrounded by a tube **22** of electrolyte copper which in turn is surrounded by, and bonded with a tube **23** of steel. The space **24** around the steel tube is filled with incompressible medium such as water. The water space is peripherally limited by the tubular workpiece **25** of steel to be widened. The magnetic field of the expansion coil **21** exerts pressure upon the externally steel-reinforced tube **22** of copper. The pressure is propagated through the enclosed quantity of water as a shock wave and acts upon the tubular workpiece **25**.

In the embodiment shown more specifically in FIG. 4, the interspace **24** is shown connected with nipples **27***a* and **27***b* for the supply and discharge of water. The tubular workpiece **25** rests against the inner periphery of a die structure composed of separable parts **28***a*, **28***b*. The above-described pressure wave causes the workpiece **25** to be widened so that its material is forced into recesses **29***a* of the die. These recesses communicate with a manifold channel **29***b* which communicates with a nipple **29***c* for connection to a vacuum pump. The terminal straps of the expansion coil **21** are denoted by **30***a* and **30***b* respectively. The annular interspace is sealed by means of a rubber disc **26***a* and a gasket ring **26***b*.

FIG. 5 illustrates how the invention may be applied for deep drawing of a workpiece. Denoted by **31** is the work coil which in this case is a flat coil of the spiral or pancake type. Closely adjacent to the coil **31** is a circular sheet of electrolyte copper reinforced on top by a sheet **33** of steel. Denoted by **34** is the interspace filled with incompressible fluid medium such as water. The workpiece **35**, constituted by a circular disc of sheet material, is located adjacent to a shaped metal structure **36** which has recesses **37**, for example of semi-circular cross section. The part **36** consists of a part that is to become bonded with the workpiece material **35** to form an integral article or component therewith. The magnetic field of the flat coil **31** imposes upon the steel-reinforced sheet **32** of electrolyte copper a pressure which causes a shock wave to be propagated through the water onto the workpiece **35**, for example of steel. As a result, material of the workpiece **35** is forced into the recesses of the body **36** to remain attached thereto. It will be understood that the same method is applicable if the workpiece **35** is tubular, in which case the components **31, 32, 33** and **36** are likewise tubular in the manner apparent from FIGS. 1 and 2.

In the more detailed illustration of a device embodying the essential components of FIG. 5, the recesses **37** are shown connected with a nipple **38** for connection to a vacuum pump, and the confined space **34** for the pressure transmitting liquid is in communication with nipples **39** and **40** for supplying and draining the liquid. The terminal straps of the flat coil **31** are denoted by **40** and **41**. The device is mounted on a support **42** with the aid of two columns **44** and **45** and a pressure bar linked to column **44** and engaged by a nut **46** which is in threaded engagement with the column **45**. This mounting permits firmly clamping the magnetic forming device proper against the support **42**.

It will be recognized from the above-described embodiments that the distance between the sheet member of electrolyte copper and the workpiece, once adjusted and fixed, remains constant. This prevents the occurrence of a pressure reduction prior to the moment where the coil current reaches its maximum value.

A further advantage of the method and devices according to the invention is the fact that workpieces of relatively low electrical conductivity can be shaped and otherwise formed without the use of displaceable driver sheets. Furthermore, no field concentrators are necessary for workpieces having different external dimensions, because the width of the space for confining the incompressible medium is not critical. Consequently workpieces of different diameters can be subjected to magnetic forming with the aid of one and the same work coil.

By virtue of the invention, there is further achieved a uniform distribution of pressure exerted by the deep-drawing coil upon the workpiece, whereas with the known methods there occurs a pressure minimum in the center of the work coil.

The invention also affords applying repeated capacitor discharges for the progressive forming of a workpiece without the necessity of providing a new driver member or a new field concentrator prior to each repetition. The novel method further permits achieving a considerably higher efficiency than the known methods and, as shown, is applicable for free forming as well as for the bonded forming of workpieces.

To those skilled in the art it will be obvious upon a study of this disclosure that various modifications may be made with respect to arrangement, materials and operation and hence that the invention may be given embodiments other than particularly illustrated and described herein, without departing from the essential features of the invention and within the scope of the claims annexed hereto.

I claim:

1. Device for forming metallic workpieces with pulsed magnetic fields comprising a work coil energizable by passage of current discharges therethrough for producing a pulsed magnetic field, said work coil having a surface adapted to face a workpiece, a mechanically stable member and a member consisting of material having high electrical conductivity connected to one another at mutually engaging surfaces thereof, said members having another surface respectively, the other surface of said member of high electrical conductivity being in close engagement with the workpiece-facing surface of said work coil, the other surface of said mechanically stable member being so disposed as to be in spaced relationship to the workpiece, and an incompressible fluid medium completely filling the interspace between the other surface of said mechanically stable member and the workpiece for coupling said members to the workpiece and exerting

upon the workpiece a forming pressure due to shock waves produced by the coil magnetic field.

2. Device according to claim 1, wherein said member of high electrical conductivity is a tube of electrolyte copper, and said mechanically stable member is a steel tube disposed coaxially to said copper tube, the inner surface of said copper tube being firmly bonded to the outer surface of said steel tube.

3. Device according to claim 1, wherein said member of high electrical conductivity is a tube of electrolyte copper, and said mechanically stable member is a steel tube disposed coaxially to said copper tube, the outer surface of said copper tube being firmly bonded to the inner surface of said steel tube.

4. Device according to claim 1, wherein said member of high electrical conductivity is a plate of electrolyte copper, and said mechanically stable member is a steel plate, said mutually engaging surface thereof being firmly bonded to one another.

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