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APPARATUS AND METHOD OF HEATING POWDERED METALS

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FIG. 1

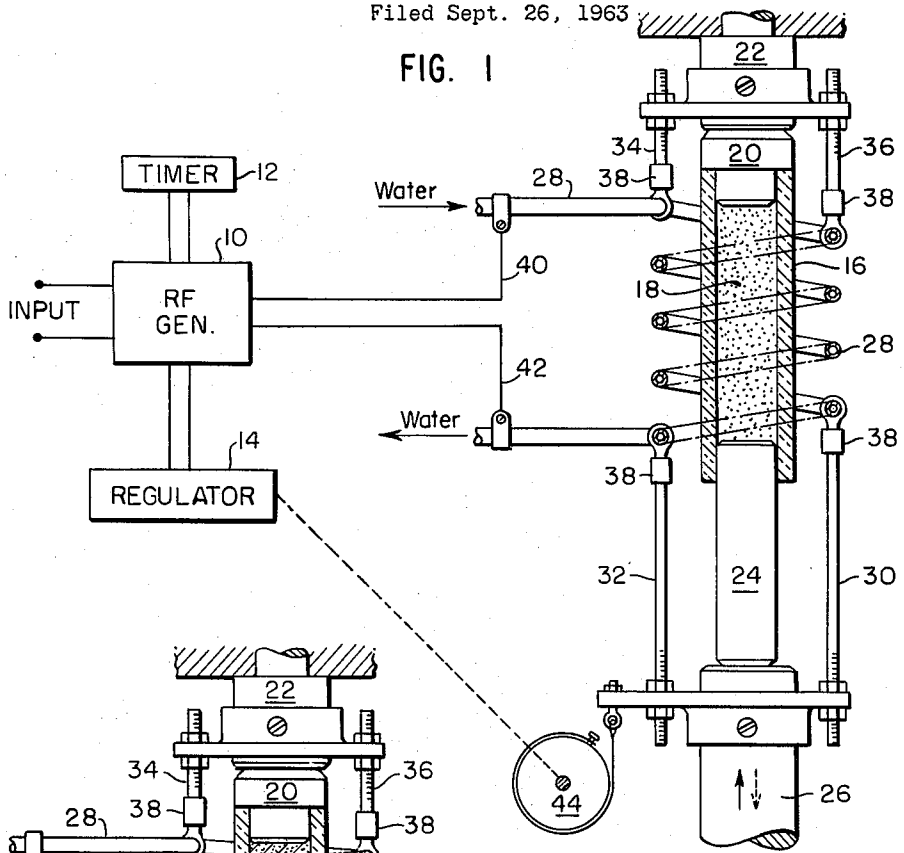
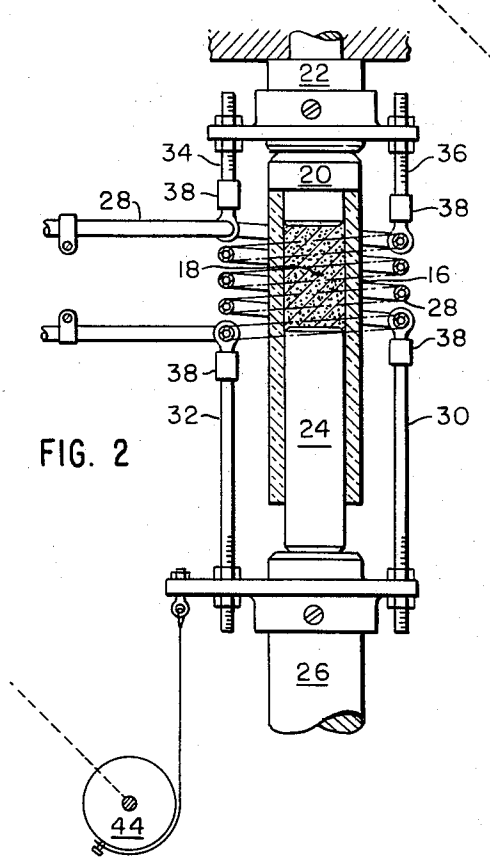


FIG. 2



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APPARATUS AND METHOD OF HEATING POWDERED METALS

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Our invention concerns an improved apparatus for and a method of heating powdered metals. In particular, our invention concerns a means of sintering and impregnating metals with lubricants. More particularly our invention relates to an apparatus for and method of forming articles from powdered metals containing heat sensitive dry lubricants.

The techniques of powder metallurgy have permitted powdered metals to be cold or hot pressed into a variety of articles such as gears, brushes, sleeves, valves, bearings, shafts, bushings, etc. Sintering of the metal particles either during or after compaction in a mold is accomplished at elevated temperatures below the fusion point of the powder for sufficient time to promote incipient fusion and the destruction of the grain boundaries or until diffusion occurs between the metal particles. Sintering and elevated temperatures can be accomplished by employing the mass of metal powders in an inductive relationship with a coil connected to a high frequency generator. The currents set up within the mass of metal powder bring about a rapid rise in temperature of the metal mass and the sintering of the mass.

Although the use of a conductive high frequency helix about the electrically conductive mass of powdered metal is satisfactory for some purposes it has disadvantages which inhibit wide commercial acceptance of this method.

In many cases a dry lubricant must be admixed with or impregnated into the powder metal mass to provide a self lubricating article, containing finely divided solid phase particles of dry lubricants uniformly dispersed through the solid sintered matrix. Many of the commercially acceptable dry lubricants which are desirable to blend with the metal powder prior to sintering are chemically degraded at a progressively rapid rate as the temperature of the sintering increases. For example, molybdenum disulfide completely oxidizes above about 750° F., while tungsten disulfide is completely oxidized at above about 850° F. Present high frequency techniques due to the rapid temperature rise and uneven temperatures within the metal mass often tend to degrade and reduce the effectiveness of heat sensitive dry lubricants.

Additionally the longer heating time and elevated temperatures obtained with high frequency coils also encourages reactions between the ambient gases such as nitrogen and oxygen with the metal mass. The formation of metal matrix oxides and materials is generally undesirable in powder metallurgy, since they give lower density articles with inferior mechanical properties.

The degradation of heat and temperature sensitive lubricants and the reaction of the metal mass with atmospheric gases is further promoted by uneven heat distribution within the metal mass which is often accompanied by a waste in electrical energy. For example, in a hot pressing operation there are no provisions made for maintaining uniform high frequency energy as the volume of the electrically conductive particles changes with compaction in the mold. Since reductions in volume of the packed particles in a mold may change on compaction from 50 to 90 volume percent or more depending upon the particles and their grain size, significant unevenness in heat distribution often occurs and a lack of uniform sintering temperatures through the compacted mass leads to unsatisfactory molded articles with poor properties.

It is therefore an object of our invention to provide a method of heating powdered metal compositions which minimizes chemical degradation of the composition.

Another object of our invention is to provide an apparatus for and a method of maintaining efficient and uniform heat distribution in a metal mass during a hot pressing operation.

A further object of our invention is to provide means for forming powdered metal articles containing heat sensitive dry lubricants.

Other objects and advantages of our invention will be apparent to those skilled in the art from the following detailed description of our invention taken in conjunction with the accompanying drawing wherein:

FIGURE 1 is a partially schematic and sectional view of an apparatus for heating by a high frequency coil and compaction in a die of a mass of metal powder showing the position of the coil and mass prior to compaction;

FIGURE 2 is a sectional view of a portion of the apparatus of FIGURE 1 showing the position of the mass and coil after compaction.

In one embodiment of our invention we have discovered that effective heating and sintering of electrically conductive dielectric lossy particles such as a mass of metal powder or doped plastics such as plastics containing carbon particles, etc. may be accomplished by employing pulsating high frequency induction heating. We have found that the employment of continuous high frequency energy to a mass of metal particles for a period of time sufficient to reach proper sintering temperatures (e.g. 500 to 2500° F.) permits the electrically conductive metal particles to rapidly increase in temperature and to transfer all or a substantial portion of this heat to the heat sensitive materials blended with the metal powders.

We have discovered that the use of a high frequency energy for short periods of time in a cyclic manner such as from ½ second to 20 seconds or more permits elevated temperatures to be obtained in the metal powders without significant heat transfer to the nonelectrically conductive particles of the blend such as the dry lubricants. Self lubricating particles such as calcium fluoride, molybdenum disulfide, tungsten disulfide, graphite, diamond dust, boron nitride, and other metal sulfides and metal compounds are normally not electrically conductive. The powdered metals of the matrix are electrically conductive and should have sufficient resistivity so that it is a dielectric lossy material. The heat transfer of the heat created by the high frequency energy in the metal particles to the dry lubricants and to the ambient atmosphere is significantly reduced, when the high frequency is employed in a pulsating manner. This reduction in heat transfer permits dry lubricants and other materials normally degraded such as oxidized at conventional sintering temperatures to be incorporated into sintered articles without excessive decomposition. Further, our technique reduces reactions between the atmosphere and the metal matrix.

The time of the pulses depends upon the nature of the

materials employed, but we have found that relatively short periods of from 1 to 10 seconds are often quite successful. Pulsing high frequency is usually employed in a hot pressing operation, i.e., where compaction and sintering is accomplished in one operation. The mass of powdered metal is usually placed in a nonconductive mold and the mold surrounded by a water cooled conductive helix of copper. High frequency energy of from 1000 to 5 to 10 megacycles may be used, but normally 10 to 1000 kilocycles are employed. The pulses may be of uniform time or vary in time depending upon the heat transfer characteristics of the mass being sintered and the sensitivity of the material being impregnated into the mass. For example, softer metals like lead may require only 200° C. for sintering, while nickel requires 1200° F. and tungsten 2000° C. The metal powder mixtures with or without additional binder materials or additives may be compacted in a confining mold under pressures of about 2000 to 50,000 pounds per square inch or higher to form a metal powder article of predetermined structure. In cold pressing operations, that is without sintering, pressures of 35,000 p.s.i. are often used, while in hot pressing operations pressures of 3 to 15,000 are common. The compacted sintered article may be optionally heat aged and slowly or rapidly quenched in a fluid such as air, oil, water, etc., to enhance the hardening characteristics of the article.

The mixtures described can be formed into a variety of improved antifriction articles such as porous powdered metal articles, having load bearing moving or non-moving frictional surfaces where one or more of the surfaces or articles contain reservoirs or pockets of the dry lubricants or other material. The articles formed from the dry powdered mixtures can be of any predetermined shape, size or characteristics and include brushes for electrical generators, contacting switches, gears, ashpots, valve stems, tubular elongated bearing sleeves, journal and thrust bearings, solid and tubular shafts, races, retainers, bushings, etc., or other articles subject to frictional forces and having wearable destructible friction surfaces. In the articles so formed the dry lubricant may be evenly dispersed throughout the article such as uniformly throughout the metal matrix. Where desired the lubricant may be incorporated only into particular areas of the article such as the surface areas or other areas of the article subject to particular severe frictional forces.

In one embodiment of the invention the matrix material comprises any electrical conductive material containing minor amounts of nonelectrically conductive heat sensitive materials. For example, powdered metals, metal alloys and metal-containing compounds capable of being compacted and sintered to form a solid metal-containing matrix such as by conventional powder metallurgical methods may be used. The metals employed include those relatively soft metals, the hardest steel tool metals and metal alloys. The powdered metals employed can thus include those metals such as tin, lead, zinc, copper, nickel, iron, cobalt, aluminum, etc., and metal alloys containing trace or minor quantities of property modifying metal constituents such as copper, tin, zinc, lead, iron, chromium, cadmium, magnesium, palladium, platinum, rhodium, vanadium, nickel, cobalt, tungsten, molybdenum, aluminum, manganese, etc., and combinations thereof either with or without other additives and dry lubricants such as metal sulfides, boron nitride, graphite and the like.

The dry lubricants can be thoroughly admixed with the metal or metal alloy powder by hand or more efficiently by high-speed powder blending machines. Good results are commonly obtained by having the metal powder particles of larger average diameter than the dry lubricant powder with which it is admixed. The quantity of the heat sensitive dry lubricant to be admixed with the metal powder depends on the amount and degree of lubrication desired and the particular conditions under which the article is to be employed. Commonly the amount of heat sensitive nonelectrically conductive materials employed will vary from about 1 weight percent to about 35 weight percent such as between 3 to 25 weight percent of the matrix. Generally in self-lubricating metal alloy compositions the tensile strength elongation, and compressive strength increase with decreasing amounts of dry lubricant, while as the amount increases the coefficient of thermal expansion and electrical resistivity increases and the hardness decreases.

In another embodiment of our invention we have found that uneven heat distribution during a hot pressing operation can be substantially reduced or eliminated by varying the length of the high frequency coil about the metal mass with the compaction of the metal. This technique also permits heat sensitive materials such as lubricants, antioxidants, resins, etc., to be blended with and impregnated into the powdered metal during hot pressing and reduces undesired reactions between the sintered metal matrix and the pressing atmosphere. Our apparatus allows either continuous or pulsating high frequency energy to be employed. Pulsating energy and varying the coil length with compaction is particularly useful where materials are used that are highly sensitive to heat and thus our apparatus permits a wide range of new materials to be considered for use in powdered metallurgy.

FIGURE 1 shows a high frequency heating apparatus of our invention which includes: a high frequency RF generator **10** such as a 20 kilowatt generator connected to power input source (not shown), a timer **12** and an input power regulator **14**. The timer **12** permits RF energy to be generated in a timed cyclic manner as heretofore described. The input power regulator **14** or other variable means is used to control the generator **10**. In practice the input power control **14** can be a powerstat between the input rectifier tube and the primary of the generator transformer to control the voltage to the primary and thus act as a variable transformer. Our apparatus includes an elongated cylindrical mold **16** composed of graphite, ceramic, quartz, or other electrically non-conductive material which forms an internal chamber in which electrically conductive particles of lossy dielectric properties such as powder metal **18** are loosely packed. The mold has at one end a top insert plug **20** which rests against a non-movable anvil **22** and has at the other end a slidable reciprocating piston **24** mounted on a vertically movable anvil **26**. A hollow helix **28** of copper tubing or other RF conductive material of a flexible nature is mounted extendably about the mold **16**, with the longitudinal axis of the coil the same as the axis of the mold **16**, and the length of the coil being the length of the loosely packed powdered metal **18** in the mold **16**. The coil or helix **28** is supported on either side, both top and bottom, by threaded elongated vertical support rods **30**, **32**, **24**, and **36**, which at one end are fastened to either side of the coil **28** through electrical insulator bushings **38**. The other ends of each pair of support rods are threadably attached to the movable **26** and non-movable **20** anvils respectively, to permit rapid adjustment of the coil length with different mold lengths. The coil is connected through electrical leads **40** and **42** to the output of the RF generator, while in operation water or other fluid cooling medium is circulated through the helix to prevent overheating. Secured to the base of the movable anvil **26** through an eyelet screw is one end of a spring return pulley **44** the other end of which is fastened to the control knob of the power control **14**. This system permits the variation of the power of the RF generator **10** with the movement of the piston **24** and anvil **26**.

In a hot pressing operation powdered material such as metal powder **18** with or without a heat sensitive material is loosely packed in the mold **16**, the top plug **20** inserted, and the top anvil **22** lowered into position and the support rods **34** and **36** attached thereto and the coil **28** adjusted to the length of the powder **18** in the mold **16**. The

powdered material is then compacted and sintered in one operation in the mold, although it is also within the scope of our invention that the powder may be compacted to a predetermined degree and then sintered or compacted and sintered. Hot pressing is accomplished by the movable anvil **26** and the piston **24** moving slowly upwardly, while the sintering is accomplished by the continually or pulsating high frequency energy furnished to the coil **28** from the generator **10**. In our apparatus as the piston moves upwardly to compact the powder giving a progressively shorter length and small volume of powder in the mold, the longitudinal length of the surrounding coil **28** is correspondingly decreased or compressed to maintain the same inductive relationship between the coil **28** and the powder core **18**, yielding better and more even heat distribution and control. In our apparatus upper and lower electrical limit switches or other means may be used to automatically initiate and stop the flow of electrical energy to the coils depending upon the coil position. Our invention allows the flexible heating coil such as a high frequency coil described to vary in longitudinal length with the amount of compaction within the mold. For example, as shown more fully in FIGURE 2, the 50% compaction of the powdered metal **18** in the mold **16** resulted in a corresponding decrease in the length of the coil **28**. Thus in FIGURE 1 where the powder is loosely packed the coil **28** extended throughout its length, while in FIGURE 2 the powder is in a compacted or dense condition the coil **28** has been compressed to a shorter length to correspond to the length of the dense mass.

Additionally, even heat distribuition and superior heat control during hot pressing can be accomplished by the variation of the power of the generator with the compaction of the material. Thus in operation as the anvil **26** moves upwardly to compact the powder **18** the pulley decreases the power of the generator **10** by moving the dial knob of a powerstat or control knob on the energy control **14** to maintain even heat distribution throughout the compacting mass. When the anvil moves downwardly the return spring of the pulley returns the energy to the same level. As shown in the drawing the pulley decreases the energy output of the generator **10** as the anvil **26** compacts the powder **18** thus reducing the RF energy to the coil **28**.

Further in our apparatus the timer of either a mechanical cam operated or electrical type can be employed to give timed pulses of RF energy to the coil **28** rather than continuous energy. The timer can be preset for ½ second to 5 min. pulses depending on the nature of the material to be hot pressed. The timer or the pulsation of high frequency energy can be used with the means for varying the output energy with compaction i.e. the pulley system, or may be used alone. The timer can also be operated in response to limit switches on the anvils so that pulsation will start and stop depending on the position of the coil **28** about the mold **16**.

Although our invention has been described with regard to metal powders and high frequency coils it is of course recognized that our apparatus will have utility with other materials such as powdered resins, glass and the like where electrical or other heating coils are employed to provide elevated temperatures and the material change in volume during the heating operation.

What we claim is:

1. A hot pressing apparatus which includes: a source of energy; a mold characterized by an internal mold cavity capable of containing a loosely packed powdered material to be compacted; a heating coil in communication with said source and about and in a heat exchange relationship with the powdered material in the mold cavity; means to compact the powdered material in the mold; and means to vary the length of the heating coil in heat exchange relationship with compaction of the material whereby uneven heat distribution during compaction is reduced.

2. An apparatus for fabricating sintered articles which apparatus comprises in combination:

a source of high frequency electrical energy;

a mold characterized by an internal cavity adapted to contain particles to be compacted and sintered;

means to compact the particles in the mold cavity into the desired form;

a coil in electrical communication with said source of high frequency electrical energy, said coil encircling the mold cavity and in an inductive relationship with the particles in the mold cavity to permit sintering of the particles; and

means to change the longitudinal length of the coil during the compacting of the particles.

3. The apparatus of claim **2** which includes timing means in electrical communication with the source of high frequency electrical energy to provide for predetermined timed pulses of electrical energy to the coil.

4. The apparatus of claim **2** which includes means to vary the power of the high-frequency electrical energy supplied to the coil with the compaction of the particles in the mold cavity.

5. An apparatus for fabricating sintered metal articles which apparatus comprises in combination:

a source of high frequency electrical energy;

a mold characterized by an internal cavity adapted to contain powdered particles to be compacted and sintered;

means to compact the particles in the mold cavity which includes a slideable reciprocating piston;

a deformable coil in electrical communcation with the source of high frequency electrical energy, said coil spaced apart from and encircling said mold cavity and in an inductive relationship with the particles in the mold cavity;

means to support the coil about the mold cavity said means secured to said piston for movement therewith; and

means to impart reciprocating movement to said piston whereby the longitudinal length of said coil about the mold cavity is proportionally reduced as the particles within the mold cavity are compacted and sintered.

6. The apparatus of claim **2** which includes control means to control the power of the source of high-frequency electrical energy and means to connect the control means to the movement of the piston whereby the input power is adjusted with the compaction of the particles in the mold.

7. In a method of forming a compacted sintered article which includes the steps of compacting in a mold cavity a mass comprising electrically conductive particles and sintering said particles during compacting by high-frequency electrical energy from a coil placed in an inductive relationship with the mass of particles the improvement which comprises: maintaining a substantially constant inductive relationship between the coil and the mass of particles during the compaction and sintering by varying the form of the coil thereby promoting more even heat distribution within the compacted sintered article.

8. The method of claim **7** which includes changing the power of the high-frequency electrical energy progressively as the particles are compacted.

9. The method of claim **7** which includes pulsating the high frequency energy during compacting in timed periods of from ½ second to 5 minutes.

10. The method of claim **7** wherein the mass comprises powdered metal particles and from about 1 to 30 weight percent of electrically non-conductive dry lubricant particles.

11. The method of claim **10** wherein the dry lubricant is a temperature sensitive lubricant capable of reacting

with oxygen at elevated sintering temperatures and which method includes reducing the power of the electrical energy and pulsating the power in predetermined short timed periods to reduce significantly heat transfer from the particles to the dry lubricant.

12. The method of claim 7 wherein the longitudinal length of the coil about the mold cavity is reduced progressively with the compacting of the particles in the mold cavity.

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REUBEN EPSTEIN, *Primary Examiner.*