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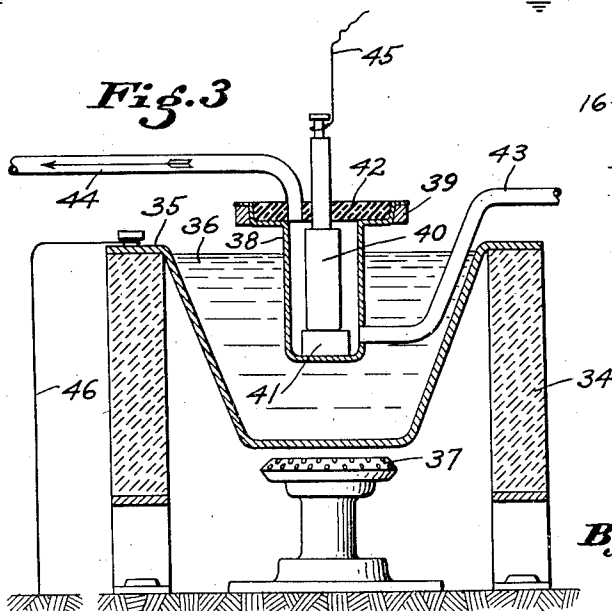
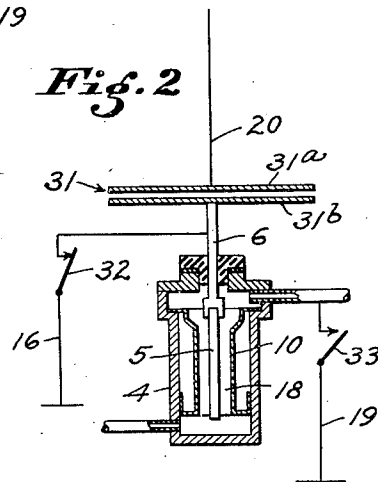
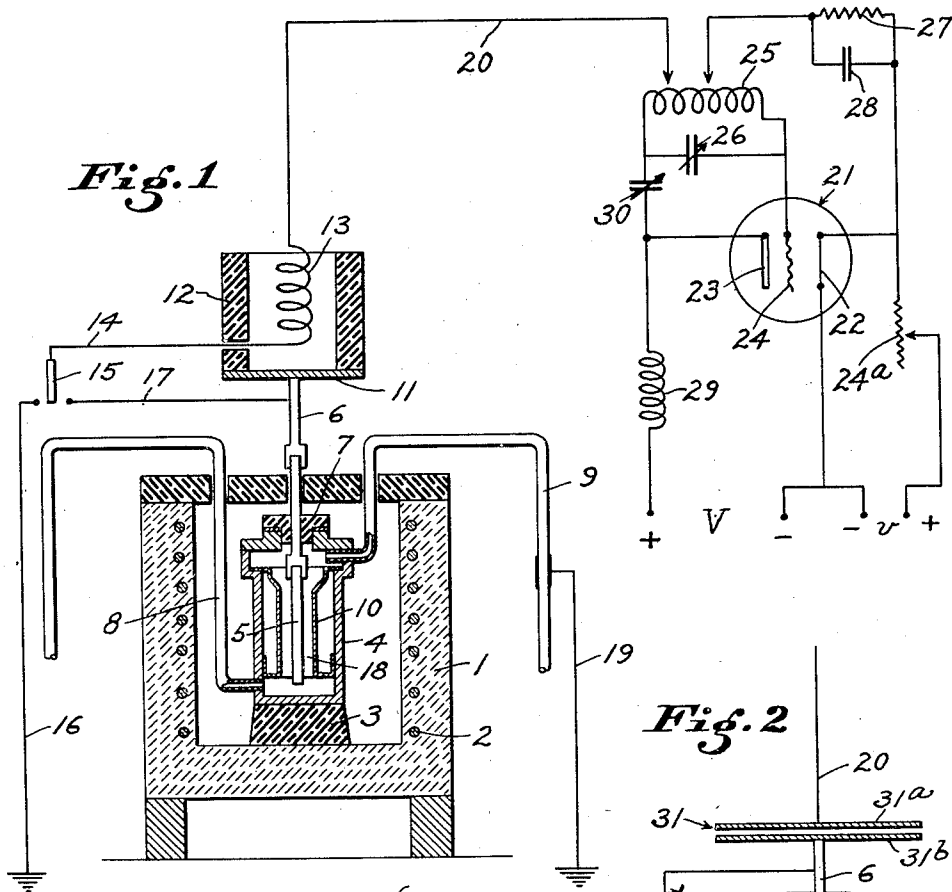
G. MAHOUX

1,939,712

TREATMENT OF METALS AND ALLOYS

Filed Aug. 2, 1930

2 Sheets-Sheet 1



Inventor:
Georges Mahoux
By *Hoguet Mery*
Attorneys.

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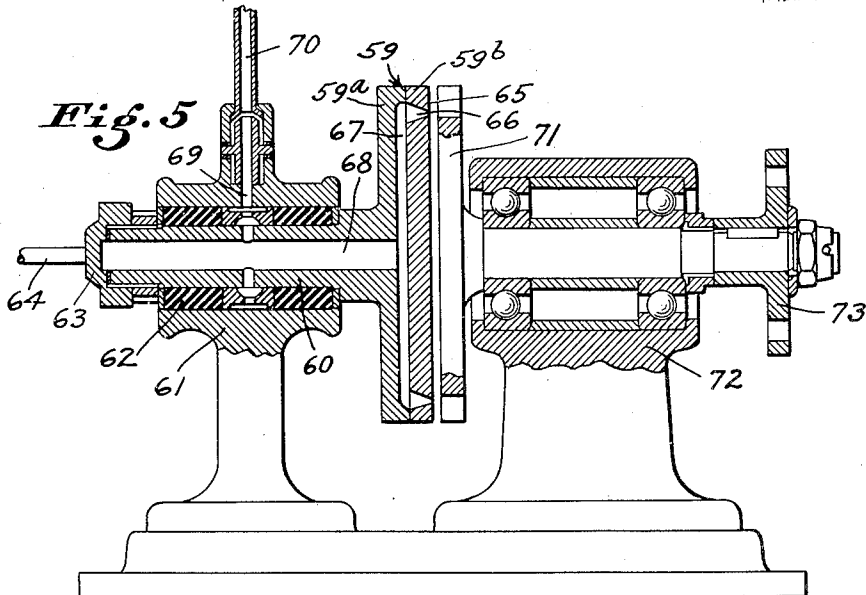
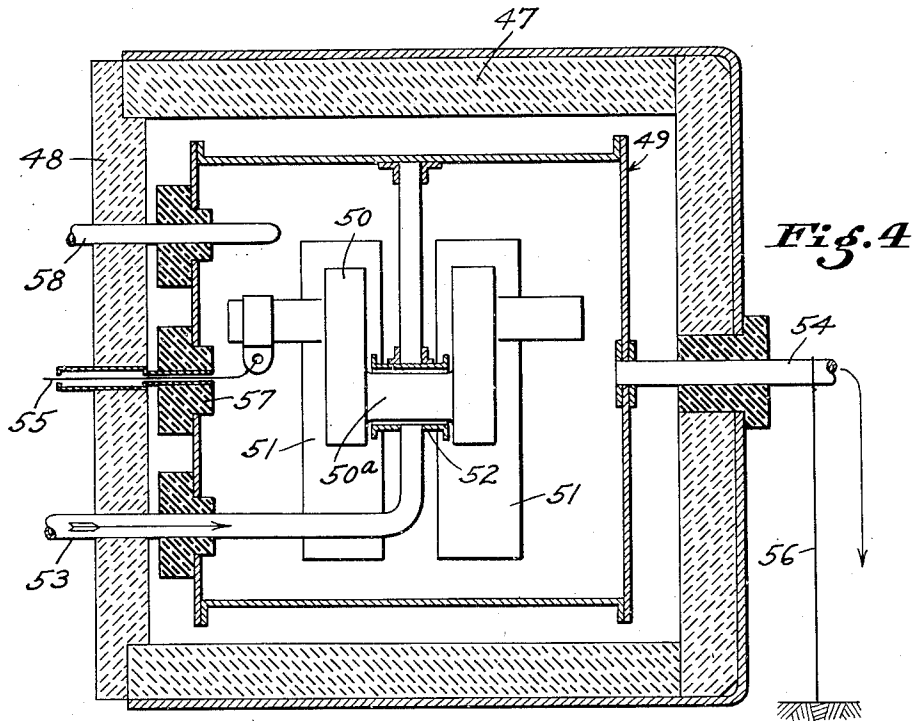
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TREATMENT OF METALS AND ALLOYS

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2 Sheets-Sheet 2



Inventor:
Georges Mahoux
By Hoguet Peary
Attorneys.

UNITED STATES PATENT OFFICE

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TREATMENT OF METALS AND ALLOYS

Georges Mahoux, La Garenne, France

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and in France August 8, 1929

24 Claims. (Cl. 148—10)

The present invention relates to the treatment of metals and alloys, and more particularly steels and ferrous alloys, to produce a change in the physical or the physical and chemical state of the metal.

various metals and alloys to effect a surface alloying through introduction of a metal, metalloid or alloy or a mixture of metals and metalloids into the surface of the metal body being treated. Other applications are pointed out in the appended description and still others will suggest themselves to one skilled in the art.

The usual process of cementation is carried out at a high temperature and is necessarily accompanied by the changes of crystalline structure resulting from the heating of a steel or ferrous alloy to a temperature above the critical transformation temperature and then cooling, i. e., heat hardening. Stresses are also set up in the metal body which, especially when the metal body or article happens to be of irregular outline, causes warping and other deformations so that after the cementation treatment it is often necessary to machine the metal to bring it to the correct size, and this is very difficult owing to the hardness of the surface portions. Moreover, such machining does not relieve the great stresses set up in the article during the heat treatment and these cannot be relieved by a re-heating treatment since this would at the same time soften the hardened surface.

One of the advantages of applying the present invention in cementation resides in the fact that the treatment can be carried on at temperatures below those producing heat hardening, i. e., below that of structural transformation on heating, and even at temperatures sufficiently below the transformation temperature to insure retention in the steel of the desirable structure produced by a previous heat treatment. It becomes possible, therefore, to utilize steels containing in their pretreated state a proportion of carbon sufficient to insure that any desired mechanical characteristics can be imparted to the portions under the hardened surface by a suitable heat treatment compatible with the heat treatment required to effect the surface hardening. The metal articles being no longer subjected to heat deformations can now be machined or otherwise be brought to size before being surface hardened. Moreover, the carbon introduced when operating according to this invention can be made to diffuse gradually from the surface towards the interior thus avoiding the tendency to scale which is a characteristic of the old processes of cementation.

When the surface hardening is to be obtained by the incorporation of nitrogen the present invention makes it possible to form a surface layer that is very hard in a relatively short time as com-

The invention is based on the discovery that if a body of metal is subjected to the action of vibrations, either electrical or mechanical, having a high frequency, i. e., of the order of ultra audible sound waves, or higher, migration of molecules within the metal body or from the surrounding atmosphere or adjacent bodies to such body and vice versa is caused to take place. It thus becomes possible by providing a suitable surrounding medium to so alter the physico-chemical equilibrium relations previously existing between the body and its environment as to produce a pronounced change in the chemical composition of the metal, and particularly of the surface portions exposed to such surrounding medium. But even when no change in the chemical composition of the metal is desired and, therefore, no environment intended to promote such change is provided, marked improvement in the physical structure of the metal, due it would appear to molecular migrations and re-arrangement within the metal body, is produced by subjecting the metal to the high frequency vibrations.

The rate at which such changes take place will, of course, vary with the temperature and with the metal being treated. However, one very important feature of the present invention resides in the fact that by subjecting the metal body to high frequency vibrations in conjunction with a heat treatment various operations, such for example as those involving surface hardening or alloying, can be carried on at relatively low temperatures or completed in a relatively short period of time as compared with the existing practice, thus making it possible to preserve certain desirable properties that would be destroyed at the high temperatures heretofore required, or to effect certain improvements in structural or physical properties that would not be possible with the existing practice. The present invention may be advantageously applied, as illustrated more fully by the specific embodiments hereinafter set forth, in the treatment of steels and ferrous alloys to effect surface hardening, as by cementation or nitriding, or a combination of cementation and nitriding; in the treatment of cast iron to produce a nitride hardened surface or to produce surface decarburization which may, if desired, be followed by surface hardening or other surface treatment; and in the treatment of

pared with present practice. A nitrided case produced according to this invention has the further advantage that there is better diffusion of the nitrides from the surface inwardly. Moreover, a very satisfactory nitrided surface or case may be produced by the use of ordinary carbon steels containing no special alloying elements.

For example, if one subjects a nickel-chromium-molybdenum steel body to a current of ammonia gas while maintaining the temperature at about 500-520° C., that is to say below the peritectic temperature and while subjecting the same to electric oscillations of the frequency of ultra audible sound, the steel body absorbs a part of the nitrogen of the ammonia gas forming a nitride layer or case on its surface. This nitride layer is characterized by a gradual diffusion into the underlying metal thereby avoiding a sharp line of demarcation such as is sometimes observed when nitriding according to the existing practice.

If the ammonia gas is replaced by illuminating gas, for example, it is possible by suitably controlling the oscillating current and maintaining the temperature at say 530° C. to form a layer of hard cementite on the metal article being treated. By using a mixture of ammonia and illuminating gas, a hard layer composed of a mixture of nitrides and cementite may be formed. A hard layer of the thickness sufficient for the applications to which such materials have heretofore been put may be obtained in less than 15 hours whether the treatment be one of nitriding or one of cementation, or a combination of the two.

The hardened elements incorporated into the metal body or article undergoing treatment may come from solid, liquid or gaseous substances. The process permits equally well the direct incorporation, either separately or in any desired combination, of solid bodies such as boron, aluminum, silicon, chromium, manganese, nickel, zinc, cadmium, or other material intended to impart to the article special properties as regards hardness, heat resistance,inoxidizability, etc.

As pointed out above, under the action of high frequency vibrations there is a migration of one or more elements such as carbon, nitrogen, etc. from the hardening agent toward the piece being treated. On the other hand, if one submits a strongly carburized metal article, such for example as a cast iron cylinder, to the action of these vibrations while surrounded by a non-carburizing medium such as soft iron filings, or while simply passing a current of air over the metal article, the carbon is made to diffuse out of the cast iron until the surface becomes decarburized to the desired degree and can then if desired be hardened or otherwise treated with a suitable addition agent.

The high frequency vibrations may be produced in various ways and applied to the article to be treated under widely varying conditions. The benefits of the present invention may be obtained by operating so as to subject the metal to vibrations of a frequency of the order of 37,500 cycles per second as the lower limit and up to more than 10,000,000 cycles per second. I prefer to operate at the higher frequencies, namely, from 3,000,000 to 10,000,000 cycles per second. Vibrations of the order herein contemplated may be produced mechanically, electromagnetically or electrostatically. Alternatively, the metal article may be subjected to sound waves of the order of ultra audible sound.

One advantageous method of applying the high frequency vibrations consists in establishing a

variable electrostatic field between a metallic object and the metal object to be treated, such objects being so associated as to function as a condenser, the dielectric being formed by the air or by a carburizing medium, a nitrogenizing medium or any other suitable dielectric. The electric field appears by its action to supplement the effect of the high frequency vibrations. Accordingly, it is considered preferable to so operate that the article in addition to being subjected to the high frequency vibrations is subjected to the effect of an oscillating electric field.

The invention comprises further certain novel arrangements of apparatus for carrying out the process, embodiments of which apparatus are shown by way of example in the accompanying drawings, in which:

Fig. 1 is a somewhat diagrammatic vertical sectional view of an apparatus for applying the process in which mechanical vibrations of the desired frequency are produced by the oscillating current from a conventional oscillating circuit and heat sufficient to maintain the desired temperature conditions during the operation is produced by an electric furnace;

Fig. 2 is a diagrammatic vertical section of a modified form of apparatus in which the vibrations are produced by a condenser energized by the oscillating current;

Fig. 3 is a partly diagrammatic vertical sectional view of an embodiment of the apparatus in which the article to be treated serves as one of the plates of a condenser;

Fig. 4 is a vertical sectional view of still another modification of apparatus operating upon similar principles as that shown in Fig. 3;

Fig. 5 represents a vertical longitudinal section of an apparatus for mechanically producing vibrations of the order of ultra sound.

According to the embodiment represented in Fig. 1, the apparatus comprises an electric furnace 1, heated by means of a resistance 2, although it will be understood that other means of applying heat may be employed. In the furnace 1 there is placed on a base 3 of insulating material a receptacle 4, designed to contain the metal article 5 which is to be treated. This article 5 which may be of any form and composed of steel or ferrous metal of any type is held within the receptacle by means of a support 6. This support 6 passes through an insulating member 7 which serves to close the receptacle 4. A pipe 8 connects with the receptacle 4 near its base and a pipe 9 connects therewith near the upper end of such receptacle, thus permitting circulation of an active gas therethrough. A pipe or annular member 10 is advantageously disposed concentrically with the article 5 within the receptacle 4 so as to canalize the active gas around the article 5 to be treated.

The apparatus is completed by providing means for producing in the article 5 which is to be treated vibrations having the desired frequency. These may be produced by any known means, such for example as the well-known Hartley oscillator or other suitable oscillator acting upon means for producing vibrations of the desired frequency such as Piezo-electric crystals, electromagnetic or electrostatic arrangements, etc. In Fig. 1 an oscillator of the Hartley type is shown acting upon an electromagnetic arrangement.

According to the arrangements shown in Fig. 1 the vibrations are imparted to the article 5 which is to be treated by connecting the same through the medium of the support 6 to a me-

tallic disc 11. This disc is attached to the lower part of a tube 12 composed of insulating material which surrounds an induction coil 13. This induction coil 13 is connected at one end with the conductor 14 and then optionally by means of the switch 15 either directly grounded through the conductor 16 or connected through the conductor 17 with the article 5 which is to be treated. In the latter case the grounding is effected through the condenser formed by the article 5, the spaced tube 10, the receptacle 4, the pipe 9 and the conductor 19. When the process is being so operated the gaseous medium present in the space 18 serves as a dielectric for the condenser thus formed.

The induction coil 13 is supplied with oscillating current from any appropriate oscillator, such as an oscillator of the Hartley type which is illustrated by way of example, comprising the usual tube 21 having a filament 22, plate 23 and grid 24 supplying a coupling transformer 25 to which the induction coil 13 is connected by the conductor 20. Suitable sources of current are connected in the filament supply circuit *v* and the plate circuit *V*. The filament supply current is regulated by the rheostat 24a and a suitable high frequency choke coil is provided at 29. A variable condenser 26 is connected across the terminals of the coupling transformer as is usual. Likewise the low voltage filament circuit is preferably connected in known manner to the coupling transformer 25 through the resistance 27, which is shunted by the condenser 28. As is customary the choke coil 29 is provided to oppose return of the high frequency to the feeding circuit and a condenser 30 is opposed to the passage of the high voltage current to the work circuit. The operation of this type of apparatus is so well understood that a description is unnecessary.

The mode of operation is as follows: The article to be treated is brought to a suitable temperature, for example about 480° C. if a simple refinement of structure is to be effected and then the oscillator is brought into action. The high frequency currents pass through the induction coil 13 and act upon the disc 11 and the latter becomes in turn a generator of mechanical vibrations of the order of ultra audible sound, which vibrations are transmitted to the article 5 being treated, and these mechanical vibrations of the frequency of ultra audible sound and at a temperature of 480° C. act on the piece to be treated modifying its crystalline state and producing an improvement of the characteristics of the steel.

For example, the application of this treatment to austenitic steels facilitates dissolution of the austenite, changing the same into pearlite with consequent improvement of the mechanical characteristics. Further, such improvement is not confined to the surface portions but is manifested even in the deeper portions.

If, instead of producing a simple refinement, it is desired to cause a hardening of the surface, it suffices, the mode of operation remaining the same as previously, to cause the receptacle 4 to be traversed by a current of an active gas (nitrogen, ammonia, illuminating gas, oxide of carbon, etc.) or by a mixture or combination of several of these gases. The hardening operation is effected rapidly.

Owing to the switch 15 and the connection 17 it is possible to subject the article 5 which is to be treated to vibrations of the order of ultra audible sound and at the same time to the high frequency current obtained from the oscillator.

Better to display the advantages of the process I will now describe the results obtained in a concrete case, with apparatus of the type above described and represented by Figure 1.

The article 5 to be treated was constituted by a cylindrical bar ten millimetres in diameter, of nickel-chromium-molybdenum steel of which the composition on analysis was approximately the following:

	Percent
Carbon-----	0.35
Chromium-----	2.9
Nickel-----	3.5
Molybdenum-----	0.5
Iron-----	Balance

The ring 10 was arranged in such a manner that the space 18 between it and the bar 5 was five millimetres. The active gas traversing this space was formed of five parts of ammonia and one part of illuminating gas. The gas was supplied under a super-atmospheric pressure of three to five centimetres of water, and at the rate of flow of about 30 liters per hour by a tube having an interior diameter of 10 millimetres. The temperature of the furnace throughout the operation was maintained at about 480° C.

The disc 11 connected to the bar 5 was 210 mm. in diameter and 10 mm. in thickness. The induction coil 13 placed 1 cm. above the disc 11 was composed of 9 turns of wire of 5 mm. diameter, the diameter of the turns being 8 cm. and their distance apart 1 cm. The length of the wave emitted by the oscillator was 38 meters. The main characteristics of the oscillator were as follows:

High tension-----	2,900 volts
Low tension-----	8 volts
Capacity of condensers 28 and 30-----	2 of microfarad
Capacity of condenser 26---	1,000 0.25 microfarad
Resistance 27-----	1,000 1,000 ohms.

With this apparatus after a period of six and one-half hours, the hardened layer obtained had a thickness of 0.3 mm. while the same steel under the same conditions but without the employment of the waves showed a hardened layer of only 0.08 mm. in seven hours. The treated bar showed a hardness measured in the Vickers machine of 310 kgs. at the surface. The center of the article had, moreover, increased in strength. In fact this article hardened and drawn, but not treated by the waves, had at the center a Rockwell hardness under 150 kilograms, of 26, and after treatment by the waves this strength was increased to 33.

In the example given the oscillating current produced the vibrations by means of the induction coil 13 but this result could, of course, be obtained otherwise, for example, by the use of a condenser 31 such as is represented in Figure 2. According to this mode of operation the conductor 20 connected to the oscillator terminates at the plate 31a of a condenser. The other plate 31b is connected mechanically for example by the support 6 to the article 5 which is to be treated. We know that the plates 31a and 31b of the condenser are, under the action of the high frequency current, the subject of mechanical vibrations of the frequency of ultra audible sound. These vibrations are transmitted as before to

the article which is to be treated 5, the latter by the use of switches 32 and 33 being or not, according to desire, traversed by the high frequency current.

5 It should be noted moreover that in the case where the portion to be treated is traversed by the electromagnetic waves the condenser 31 may be omitted because the article 5 may itself constitute the plate of a condenser of which the other plate is constituted by the annular member 10 connected to the ground, the space 18 traversed by the active gas constituting the dielectric.

A simplified arrangement of the apparatus in which the article being treated is connected as one of the plates of a condenser is represented in Figure 3. In this apparatus 34 is a brick support on which is placed a metallic tank 35 containing, for example, molten lead 36. This tank 35 is heated by any means whatsoever, for example, by a gas burner 37 in order to keep the lead bath 36 at a temperature suitable to obtain the hardness desired.

In this tank 35 is a metallic box 38 held by suitable supports 39. The metallic cylinder or other metal article to be hardened 40 is positioned in the box 38. This cylinder is electrically insulated from the box 38 at the bottom by a block of insulating and refractory material 41 and at the top by an insulating member 42 also serving as a closure for the box 38.

The gas or the mixture of gas which is intended to form a hard layer with the steel comes into the chamber through tube 43 and escapes through tube 44.

In addition an oscillator of the usual type is connected with the cylinder 40 by means of connection 45. The tank 35 is grounded by a conductor 46. The cylinder 40 thus forms with the box 38 a condenser, transversed by the oscillating electric circuit and of which the gas forms the dielectric.

In Fig. 4 is shown another form of an apparatus showing a further adaptation of the process. A furnace 47, which may be heated electrically or by any other suitable means, not shown, is shown as provided with a door 48 for introducing the material to be treated. A box 49 formed of a suitable metal, e. g. sheet iron, is shown as positioned within the furnace. This box is preferably removable and is supported in position by suitable means not shown. In the interior of this box 49 is positioned a piece 50 intended to be treated. In the figure I have represented a crankshaft with a single throw which is to be hardened on the bearing 50a. The crankshaft 50 is supported in the box 49 by brick 51 or other support which is not conductive of electricity. About the portion 50a which is to be hardened, is disposed a tube 52 which is in spaced relation to the piece and provides a suitably restricted space about the bearing 50a. The gas to be used for producing the hardening is introduced by the pipe 53 opening between the bearing 50a and the tube 52, flows out into the box and escapes finally by the pipe 54. Suitable means (sight holes or equivalent) are provided on the pipe 54 for permitting observation of the circulation of the gases.

The oscillating current is led to the piece to be treated by any appropriate connection 55. The box 49, in which the piece is enclosed, is grounded by a connection 56. The crankshaft 50 and the connection 55 are insulated from the box 49 on the one hand by the brick supports 51 and on the other by the insulating and refractory plugs 57 which permit the passage of the connection 55 for

the oscillating current. The pyrometer 58 is introduced into the box 49 to permit observation of the temperature and to maintain it at a suitable value.

As in the next preceding example, during the entire period that the piece is exposed to the gas, the temperature is maintained at a suitable value and an oscillating current is created in the vicinity of the part to be hardened and the tube 52.

It will be understood that the length of the treatment and the intensity of the oscillating current are determined by the dimensions of the piece being treated.

The vibrations of a frequency of the order of ultra audible sound waves may be produced by purely mechanical arrangements. Such an arrangement is shown in Fig. 5. According to this mode of operation a fixed plate 59 composed of two members 59a and 59b is supported by means of a shaft 60 from the frame 61. A mounting 62 of rubber or similar material is interposed between the shaft 60 and the frame 61. On the free end of the shaft 60 there is fixed a member 63. On this member 63 there is fixed by welding or otherwise the member 64 connected to or supporting the portion to be treated.

From the plate 59 there open on its flat surface 65 and near its periphery the blast orifices 66, which preferably are regularly spaced. These blast orifices 66 open through the plate into a chamber 67 arranged between the two parts 59a and 59b of the plate. This chamber 67 is connected by the axial conduit 68 and the radial conduit 69 with a pipe 70 providing for the inflow of air or other gas under pressure.

Opposite the plate 59 there is placed a toothed wheel 71. This wheel supported by a bearing 72 is connected at 73 to an appropriate member making it possible to actuate the said wheel at a speed of rotation of about 30,000 revolutions per minute.

The jets issuing from the orifices 66 strike alternately on the teeth of the wheel 71 and into the hollows separating these teeth. There results the production in the plate 59 and the portions which are connected mechanically to it, as well as in the wheel 71, mechanical vibrations of the frequency of ultra audible sound, the frequency being dependent upon the number of teeth, the number of blast pipes and the speed of rotation of the wheel 71. The vibrations are transmitted through the shaft 60 to the portion which is to be treated by means of the members 63 and 64.

Instead of subjecting the body to be treated to mechanical vibrations produced either mechanically or electrically, or to electrostatic oscillations, the invention may be carried out by the use of electromagnetic oscillations produced by any one of the recognized conventional means, for example, by disposing the piece to be treated within an electromagnetic induction coil. Similarly the piece may be subjected to the action of ultra audible sound waves by a suitable disposition of apparatus such as will be apparent to one skilled in the art.

As mentioned above, the principle of the invention may be applied in effecting the incorporation into metals, alloys, and especially into steels and other ferrous alloys, of other metals or metal-loids or alloys. The element to be incorporated can for example be placed around the piece to be treated either in the form of fine powder or

in any other manner, as for instance by electro-plating.

Four examples are given here:

First example

5 An extra soft steel test bar was surrounded with powdered boron and submitted to vibrations of the desired frequency. The boron, although having an extremely high melting point (much
10 higher than the temperature to which it is subjected in this treatment,—about 520° C.), diffused into the metal and attained a penetration of about 0.7 mm. in ten hours.

Second example

15 A piece of extra soft steel was previously covered with a coating of chromium by electro-plating. The piece was then submitted to vibrations of the desired frequency at about 530° C. At
20 the end of about nine hours the chromium had penetrated into the piece of steel to a depth of about 0.35 mm.

Third example

25 Still another test was made with a semi-hard steel corresponding to the following analysis:

Carbon	0.7%
Silicon	0.25%
Manganese	0.5%
30 Phosphorous	0.04%
Sulphur	0.04%
Iron	Balance

35 This specimen was surrounded with a mixture of boron, graphite and copper in powdered form and was submitted to the action of the vibrations and electromagnetic oscillations at a temperature of 575° C. in a medium made up of one part of ammonia gas and four parts of illuminating gas. After nine hours of this treatment, a
40 hard layer of about 0.15 mm. thick containing principally carbon and boron was produced. Then the same specimen after removing the unabsorbed boron, etc. from the treating chamber
45 underwent a similar treatment for ten hours at 750° C. and the hard layer became deeply diffused into the body of the specimen.

Fourth example

50 A specimen of extra soft steel surrounded by powdered zinc and submitted for five hours to the action of ultra audible sound vibrations at 330° C. was penetrated by the zinc to a depth
55 of .07 mm.

Cast iron

A bar of cast iron about 55mm. in diameter and having the following composition:

Carbon	3.1%
60 Graphite	2.29%
Silicon	1.40%
Iron	Balance

was treated for ten hours at a temperature of 530° C. by means of the apparatus described in Fig. 1 but with circulating air as the gaseous medium.

65 After this experiment the specimen was covered with a non-adhering deposit of carbon about 0.3 mm. thick. A microscopic examination showed that the specimen was decarburized to a depth of 0.8 mm. The decarburized layer was clearly distinguishable by the almost complete absence of cementite patches.

75 While as above stated, the effect is more pro-

nounced when operating at elevated temperatures, it will be understood that considerable improvement may be brought about by operating at very low temperatures. For example, the following test was made on a nickel-chromium-molybdenum steel having the following composition:

Carbon	0.35%
Nickel	3.0 %
Chromium	3.0 %
Molybdenum	1.0 %
Iron	Balance

This specimen had previously undergone an oil quenching after heating to about 925° C. and had then been reheated to 500° C. and showed a hardness of 506 Brinell. It was simultaneously submitted to the action of ultra audible sound vibrations and electromagnetic oscillations without any heating for ten hours in an atmosphere made up of one part of illuminating gas and four parts of ammonia. The temperature of the specimen was maintained throughout this treatment practically at that of the surrounding atmosphere: 17° to 20° C. After this treatment,
90 the hardness of the specimen was above 556 Brinell and a microscopic examination showed the formation of a layer of cementite and nitrides of a little more than 0.1 mm. in thickness.

The experiments cited are given merely by 105 way of illustration of the principles of my invention and it will be evident to those skilled in the art that many modifications may be made both in the methods and apparatus described without departing from the spirit of my invention. 110

I claim:

1. Process of treating ferrous metals and alloys comprising subjecting the same to vibrations of a frequency of the order of ultra audible sound without establishing a marked differential between the temperature in the surface portions of said piece and the temperature in the interior portions thereof. 115

2. Process of treating ferrous metals and alloys which comprises subjecting the same to electrical oscillations of radio frequency without establishing a marked differential between the temperature in the surface portions of said piece and the temperature in the interior portions by reason of the influence of the electrical treatment. 125

3. Process of treating ferrous metals and alloys comprising subjecting the same simultaneously to the action of high frequency electric oscillations and to the action of mechanical vibrations of a frequency of the order of ultra audible sound. 130

4. Process of treating ferrous metals and alloys which comprises heating the article to be treated while subjecting the same to vibrations of a frequency of ultra audible sound without establishing a marked differential between the temperature in the surface portions of said piece and the temperature in the interior portions thereof. 135

5. Process of treating ferrous metals and alloys which comprises heating the article to be treated while subjecting the same to electromagnetic oscillations of a frequency of the order of ultra audible sound waves without establishing a marked differential between the temperature in the surface portion of said piece and the temperature in the interior portions by reason of the influence of the electrical treatment. 145

6. Process of treating ferrous metals and alloys comprising heating the article to be treated while 150

subjecting the same simultaneously to the action of high frequency electric oscillations and to the action of mechanical vibrations of a frequency of the order of ultra audible sound.

- 5 7. Process of hardening ferrous base metal articles which comprises heating the articles to an elevated temperature but below that of peritectoidal transformation of the metal under treatment while subjecting the same to vibrations of
- 10 a frequency of the order of ultra audible sound waves without establishing a marked differential between the temperature in the surface portion of said piece and the temperature in the interior portions thereof.
- 15 8. Process of treating metals and alloys which comprises heating the piece to be treated in the presence of an agent capable of giving up molecules of itself to said metals and alloys when they are vibrated rapidly in their presence, while
- 20 submitting the said piece to mechanical vibrations of a frequency of the order of ultra audible sound waves, to set up molecular migrations between said piece and said agent.
- 25 9. Process of treating ferrous metals and alloys which comprises heating the piece to be treated in the presence of an agent capable of giving up molecules of itself to said metals and alloys when they are vibrated rapidly in their presence, while
- 30 submitting said piece to electrical oscillations of radio frequency, to set up molecular migrations between said piece and said agent.
- 35 10. Process of treating metals and alloys which comprises heating the piece to be treated in the presence of an agent capable of giving up molecules of itself to said metals and alloys when they are vibrated rapidly in their presence, while
- 40 submitting the said piece simultaneously to electrical oscillations and to mechanical vibrations having a frequency of the order of ultra audible sound waves, to set up molecular migrations between said piece and said agent.
- 45 11. Process of treating metals and alloys which comprises heating the piece to be treated, in the presence of a gaseous active agent around said piece and simultaneously submitting said piece to vibrations of a frequency of the order of ultra audible sound waves, to set up molecular migrations between said piece and said agent.
- 50 12. Process of treating ferrous metals and alloys which comprises heating the piece to be treated in the presence of an active carbon-containing agent, while submitting said piece to vibrations of a frequency of the order of ultra audible sound waves, to carburize the surfaces of
- 55 said piece.
- 60 13. Process of treating ferrous metals and alloys which comprises heating the piece to be treated in the presence of an active nitrogen-containing agent, while submitting said piece to vibrations of a frequency of the order of ultra audible sound waves, to effect nitriding of the surfaces of said piece.
- 65 14. Process of treating ferrous metals and alloys which comprises heating the piece to be treated in the presence of a mixture of an active nitrogen-containing agent and of an active carbon-containing agent, while submitting said piece to vibrations of a frequency of the order of ultra audible sound waves, to produce a hardened
- 70 surface containing a complex mixture of nitrides and carbides.
- 75 15. Process of treating metals and alloys which comprises heating the piece to be treated in the presence of a metalloid-containing active agent, while submitting said piece to vibrations of the

order of ultra audible sound waves to effect incorporation of said metalloid into the surface of said piece.

16. Process of treating metals and alloys which comprises heating the piece to be treated in the presence of a metal-containing active agent, while submitting said piece to vibrations of the order of ultra audible sound waves, to effect alloying of said metal with the surface portions of said piece. 85

17. Process of treating metals and alloys which comprises heating the piece to be treated in the presence of a metal-containing active agent, while submitting said piece to electrical oscillations of radio frequency, to effect alloying of said metal with the surface portions of said piece. 90

18. Process of treating metals and alloys which comprises forming a galvanic metal deposit on the piece to be treated and then subjecting said piece to vibrations of a frequency of the order of ultra audible sound waves, to promote diffusion of said deposit into said piece. 95

19. Process of treating metals and alloys which comprises forming a galvanic metal deposit on the piece to be treated and then subjecting said piece to electrical oscillations of radio frequency, to promote diffusion of said deposit into said piece. 100

20. Process of treating ferrous metals and alloys which comprises heating the piece to be treated in the presence of an active agent, while submitting the said piece to vibrations of a frequency of the order of ultra audible sound waves, to set up molecular migrations between said piece and said active agent to alter the composition of the surface portions of said piece. 105

21. Process of treating cast iron articles which comprises subjecting said article while in a heated condition and in the presence of a carbon-absorbing medium to the action of high frequency oscillations of the order of ultra audible sound waves. 110

22. An apparatus for the treatment of metals and alloys comprising means for holding the piece to be treated and means associated therewith for producing vibrations of a frequency of the order of ultra audible sound waves in said piece without establishing a marked differential between the temperature in the surface portions of said piece and the temperature in the interior portions thereof. 115

23. An apparatus for the treatment of metals and alloys comprising a heating chamber for receiving the piece to be treated, means for heating said chamber and a piece contained therein and means associated with said chamber for producing vibrations of a frequency of the order of ultra audible sound waves in said piece without establishing a marked differential between the temperature in the surface portions by said piece and the temperature in the interior portions thereof. 120

24. An apparatus for the treatment of metals and alloys comprising a heating chamber, a metal receptacle for receiving an article to be treated disposed within said chamber, means for supporting said article in spaced relation to said receptacle and means for operatively connecting said receptacle and said article as adjacent plates of a condenser, means for circulating a gaseous medium through said receptacle, an electric oscillator, and means for passing current from said oscillator through the condenser formed as above. 125