

Aug. 26, 1958

L. J. ETTENREICH
METHOD OF CONTROLLING THE PROPERTIES OF
METALS AND METAL ALLOYS BY
IRRADIATION WITH VIBRATIONS

2,848,775

Filed Sept. 17, 1953

3 Sheets-Sheet 1

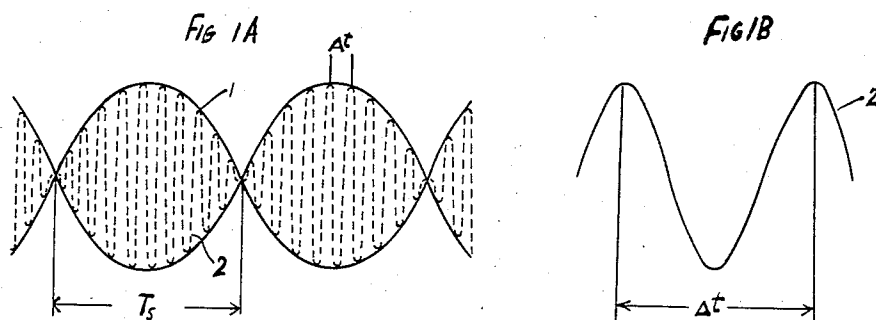
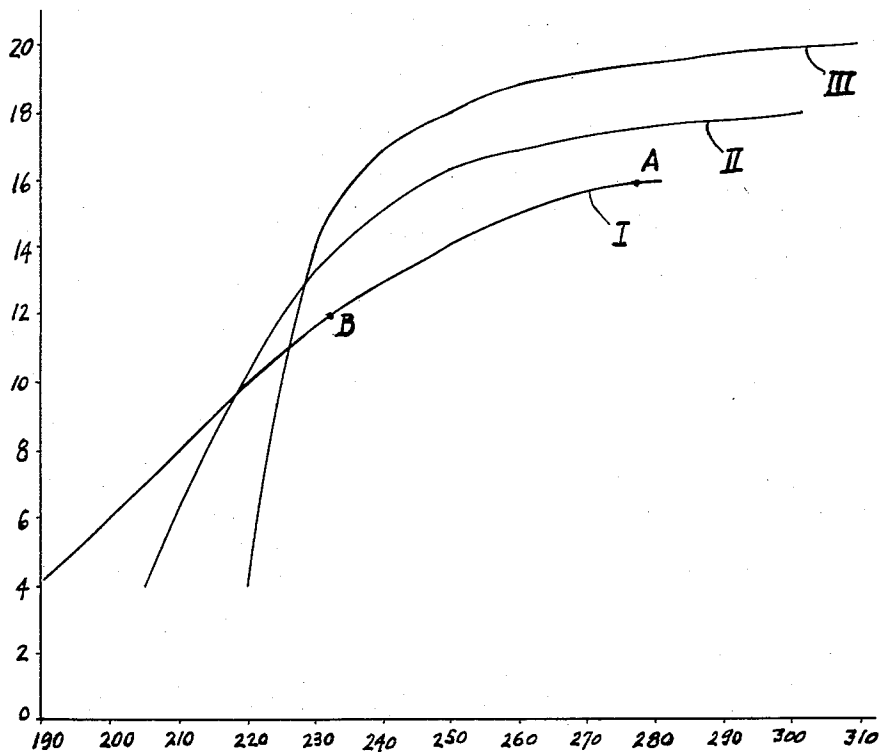


Fig 2

L. J. ETTENREICH
INVENTOR.

BY *J. Miller*
His Attorney.

Aug. 26, 1958

L. J. ETTENREICH
METHOD OF CONTROLLING THE PROPERTIES OF
METALS AND METAL ALLOYS BY
IRRADIATION WITH VIBRATIONS

2,848,775

Filed Sept. 17, 1953

3 Sheets-Sheet 2

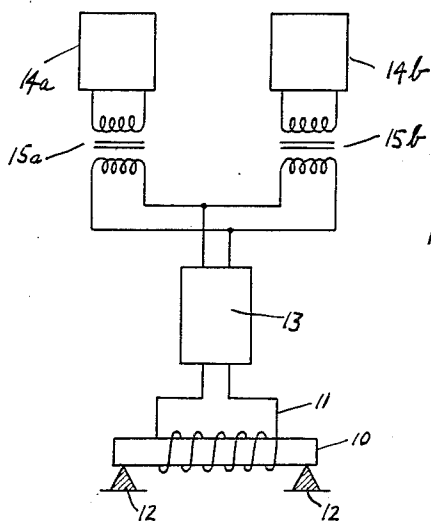


Fig 4

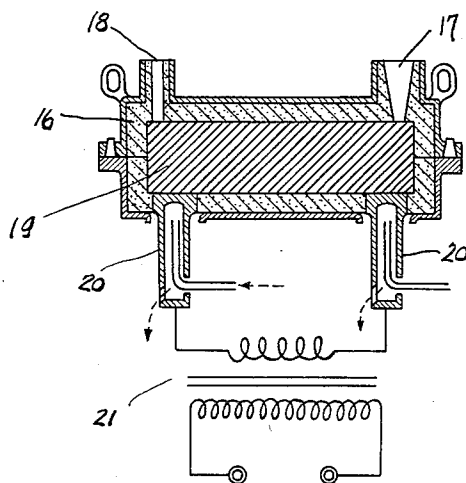


Fig 5

L. J. ETTENREICH

INVENTOR.

BY

G. Wille
His Attorney.

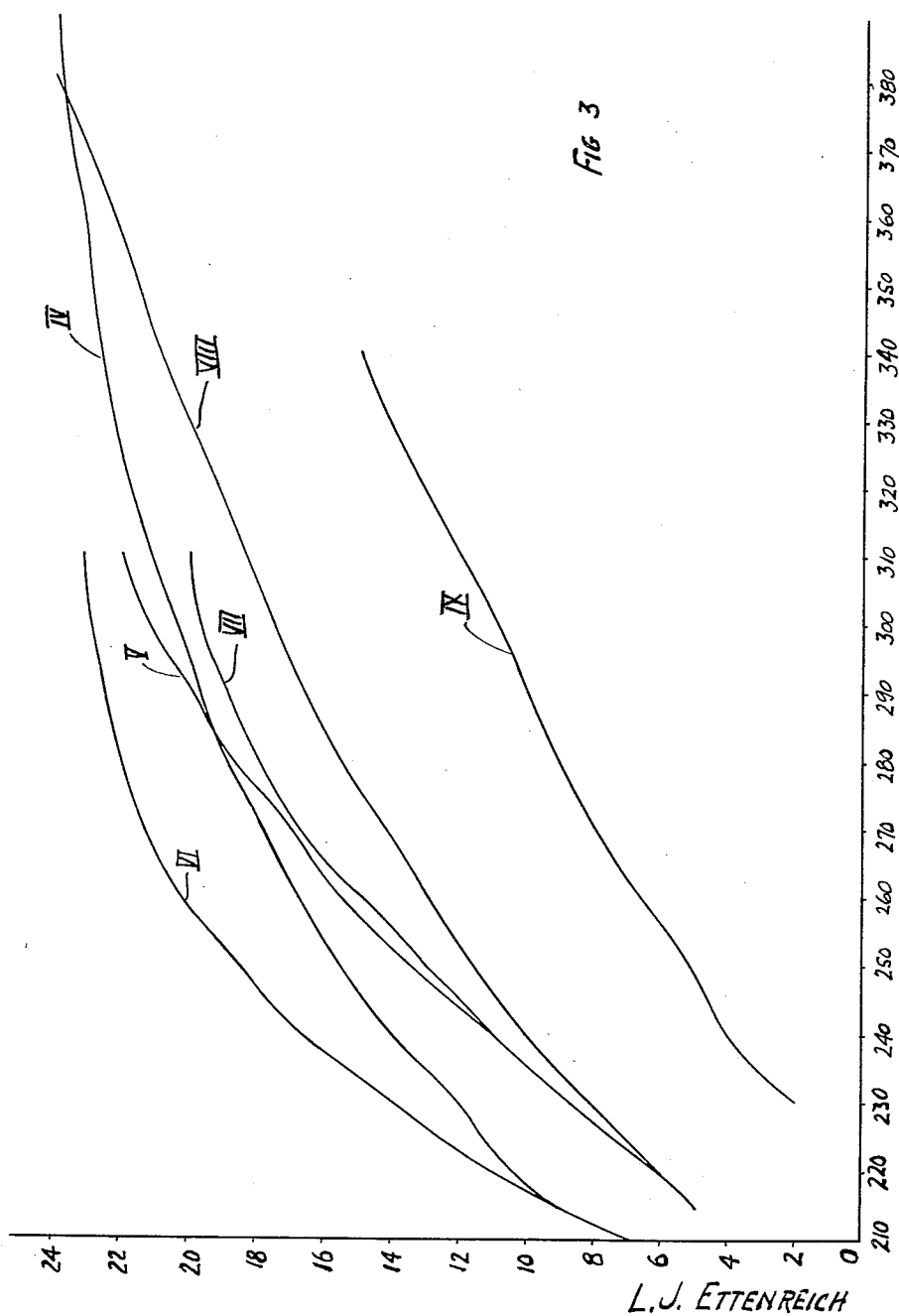
Aug. 26, 1958

L. J. ETTENREICH
METHOD OF CONTROLLING THE PROPERTIES OF
METALS AND METAL ALLOYS BY
IRRADIATION WITH VIBRATIONS

2,848,775

Filed Sept. 17, 1953

3 Sheets-Sheet 3



L. J. ETTENREICH

INVENTOR.

BY

[Signature]
His Attorney.

1

2,848,775

METHOD OF CONTROLLING THE PROPERTIES OF METALS AND METAL ALLOYS BY IRRADIATION WITH VIBRATIONS

Ludwig Josef Ettenreich, Wolfurt, Vorarlberg, Austria, assignor to Etma S. A., Panama, Panama, a corporation of Panama

Application September 17, 1953, Serial No. 380,812

16 Claims. (Cl. 22-260)

This invention relates to a method of controlling the orders of magnitude of the properties of metals and metal alloys, for example steel, by subjecting them, in their solid or molten state, at temperatures corresponding to, or above the phase conversion state to the influence of vibrations of appropriate frequencies from an external source.

An object of the instant invention is so to control the atomic and crystallographic structure of the treated material throughout the entire body of the material in accordance with predetermined requirements of hardness, tensile strength and grain size, of which the material as judged by its qualitative and quantitative composition is capable.

A further object of the invention as applied to the treatment of steel is to produce a predetermined desired solution of its carbon constituent in the iron thereof, together with the attendant physical properties in the steel, without withdrawing energy suddenly from the steel.

Still a further object of the invention as applied to the treatment of steel is to supply energy electrically, acoustically or otherwise, to the steel at temperatures at or above a determinable temperature to produce predetermined and desired physical property values in the steel which are retained by the steel at normal temperatures.

Still a further object of the invention, as applied to the treatment of steel, is to produce predetermined improved physical properties in ordinary carbon steels which improved properties are of orders of magnitude of the physical properties of alloy steels.

Still a further object of the method is to permit of the casting of metal products in their final dimensions and treating them in the cast and heated condition in such manner as to improve their physical properties without interrupting or accelerating the cooling thereof, and to retain the improvement so obtained when the cast metal products have solidified and cooled.

Still a further object of the invention, as applied to the treatment of light-alloy steels, as well as medium-alloy steels, is to improve the physical properties thereof to substantially the same order of magnitude as those presently of the more heavily alloyed steels.

Still a further object of the invention, and particularly as applied to the hardening of steel, is to eliminate present requirements in respect of the small time intervals within which the cooling or quenching must be effected to produce a required degree of hardness, and yet to obtain any required degree of hardness wholly independent of the cooling time.

Still a further object of the invention is to permit hardening carbon steels, within their hardenable range, to the very core thereof to such values as are presently associated with alloy steels.

Prior methods of controlling the values of the properties of materials, particularly metals and metal alloys, by influencing their atomic and crystallographic structure

2

have generally taken the form of heating followed by quenching, that is, have involved the extraction of energy from the material being treated. More recently, methods have been suggested of so controlling such structures in materials, metals and metal alloys, by subjecting them in heated condition to supersonic vibrations. Probably due to the high order of damping of the frequencies involved, only surface effects have been obtained rather than the desired uniform effect throughout the whole body of the material being treated. Even to produce such surface effects as the supersonic methods are capable of, considerable time was required, although as compared to methods involving quenching, the supersonic methods are based on the principle of energy addition to the material being treated. It appeared to me that the principle of energy addition to control the physical properties was basically correct, but that in these supersonic methods the source of the external energy added to the material was rather the most unfavorable one that could be used in view of the high damping rate of supersonic frequency generators. Furthermore it appeared to me that the use of supersonic frequencies not related in any fixed way to the material under treatment probably contributed to the results obtained, namely, the inadequate surface effects and the failure to produce effects uniform throughout the body treated. By subjecting bodies to the influence of supersonic frequencies, a loosening of the atomic structure as well as a decrease in the grain size was produced. Based upon theoretical considerations, since supersonic methods of irradiation produced only surface effects and since low frequencies in the audio range could readily be sustained without any damping, irradiation by the use of low frequencies might well penetrate throughout the body being treated. However, with only that knowledge and in the absence of the phenomenon first observed and recognized by myself, the use of low frequencies would appear impractical as involving too much time.

The instant invention overcomes the difficulties of the supersonic methods and is based on the following phenomenon first discovered and recognised by myself as to the characteristic nature thereof. Any body of matter, and particularly of metals or metal alloys, composed of at least two constituents, or composed of a major and at least one minor ingredient—whether such minor ingredient is found with the major ingredient in the latter's natural state or is added thereto in the processing thereof—in addition to its natural or resonant sinusoidal vibration of a given frequency, determined in the main by the major ingredient of the particular body, has a second characteristic vibration of which the frequency is dependent on the order of magnitude of the physical properties of the body produced by the minor ingredient, respectively ingredients. Only in the case of bodies of a single constituent which is substantially chemically pure has such a second characteristic vibration not been observable. This second characteristic vibration differs slightly in frequency from the frequency of the natural or resonant vibration, being always somewhat higher as observed and measured, and is also of sinusoidal wave shape. Since the two frequencies differ but slightly from each other a resultant, relatively low frequency beat vibration is produced. The natural or resonant frequencies of bodies are obviously considerably below the supersonic frequencies used in the prior methods attempting to influence and control the physical properties of bodies, and in practical cases are seldom in excess of some 3,000 cycles per second extending downwardly to a few cycles per second or less.

In the following portions of the specification and in the claims the term "natural frequency" is always used to define the lower of the two frequencies at which a

body of material of at least two components vibrates when left to itself to vibrate freely after having been set in vibration by an application of an external force and such external force has terminated.

I was the first to recognize that the beat vibrations which occur in an elastically anisotropic medium or body are related to the values of the physical properties of such body and that:

a. The frequency of the beat vibration is a function of the physical properties of the body, such as hardness, tensile strength, and grain size, varying in relation to such values, and increases with increases in the values of the hardness, tensile strength, and fineness of grain structure;

b. By impressing beat vibrations of a given frequency upon such a body, and thus also the energy of such beat vibrations, the value of the physical properties of such body may be varied since each value of the physical properties of such body corresponds to a beat vibration of a definite frequency characteristic of the particular value; and

c. To control the physical property values of the body by impressing a beat vibration of a given frequency upon such body, one of the two sinusoidal oscillations producing the beat vibration must have a frequency equal to the natural frequency of the body.

The above can be explained in greater detail as follows: By the method of my invention changes in the values of the physical properties of such bodies, particularly in the case of steel bodies, are caused by producing a forced or compulsory status in the atom lattice. The elastic anisotropy of a body is related to changes in the values of the physical properties. The magnitude of this elastic anisotropy is functionally related to the variations in value of such physical properties. When an elastically anisotropic body is excited to vibrate at its natural frequency—or even when it is caused to vibrate at a forced frequency—the waves set up in the body, as a result of the body's elastic anisotropy producing a different velocity of transmission of the wave in different directions, are divided into two components. In that the two components are coherent, i. e., have a common point of origin, and, as shown by observations and experience, are of but slightly different frequencies, they interfere with each other in the form of a beat vibration. In the physical sense a beat vibration is the resultant of two sinusoidal oscillations, the frequency of the beat vibration being the difference in the frequencies of the oscillations producing it and of which the amplitude is a periodic function of time. A beat vibration of which one component sinusoidal oscillation is the natural frequency of the body is hence designatable as a "natural beat vibration" of the body.

This natural beat vibration, and only this natural beat vibration, is characteristic of the particular value of the physical property of a body of a given material. Only this natural beat vibration, that is, the energy inherent in such natural beat vibration, can be used to vary the order of magnitude of the values of the physical properties of the body to a predetermined and desired value. Each value of a physical property, such as hardness, ductility, tensile strength and grain size for example, corresponds to and has a definite energy content. If then, the value of such physical property is to be altered, there must therefore be applied to the body at least such a quantity of energy which quantitatively totals to that of the desired value of the physical property.

My tests have uniformly shown that for a given configuration and a given material, the natural frequency remains unchanged but that the frequency of the natural beat vibration increases with the hardness of the body. Taking bodies of identical material throughout the bodies and of the same geometrical configuration and dimensions, I have tested their hardness in the untreated condition and in conditions after treatment to various de-

grees of hardness. Irrespective of the mode of treatment by which the particular hardness was produced in the body, these tests conclusively demonstrated that for all of the bodies, treated and untreated alike, the natural frequency was the same and that, as compared to the untreated body, the frequency of the natural beat vibration of the treated bodies had changed. Where the treated bodies had experienced an increase in hardness relative to the untreated body, the natural beat frequency had increased, while where the hardness of the treated bodies was relatively less, the natural beat frequency had decreased. Numerous runs of such tests with metal bodies, other than those of a single substantially chemically pure metal, confirmed the conclusion that the natural beat frequency, and thence the frequency of the second characteristic sinusoidal oscillation, is in fixed relation to the hardness of the bodies, varying in the same sense as the variations in hardness. But, as shown by handbooks on materials, since such other physical properties as grain size, tensile strength, elongation and ductility, vary in fixed relation with hardness, for all practical purposes reliable deductions are possible as to the relation of the natural beat frequency and such other physical properties.

To determine whether the natural beat vibration frequencies were constant for a given hardness irrespective of the material of the bodies, my test bodies were all of the same configuration and dimensions but either of different proportions of the same materials or of the same or other proportions of different materials. It was found that for corresponding values of hardness, the frequencies of the natural beat vibrations were not constant for all materials and proportions of constituents but were different for different body compositions, whether the difference in composition was qualitative or quantitative. Since the natural frequency of a body is a function of its composition, and hence of its modulus of elasticity and density, and in part of its geometric configuration, the conclusion follows that the frequency of the natural beat vibration is a function of the natural frequency and of the degree of hardness.

It follows that it is possible to produce in a body which, judged by its constituents qualitatively and quantitatively, is capable of having values of its physical properties different from the values they presently have, any of the differing and desired values, by impressing on the body the particular natural beat vibration of the frequency characteristic of the particular desired value of the physical property. At the same time the body should be in such condition that the effect produced by the natural beat vibration shall be retained indefinitely by the body after it is removed from the influence thereof, such as is the case on quenching heated bodies in the prior known methods for hardening metals, for example steel. In accordance with established international terminology, the term "steel" means any iron capable without further treatment of being forged. The possibility of hardening steel depends primarily on its carbon content. It will be recalled that in the usual methods of hardening steel, the steel is cooled from a certain temperature, as given by its phase diagram, lying above the critical temperature of the particular steel, the cooling being more or less rapid thereby withdrawing energy from the steel. Each such certain temperature corresponds chemically to a certain state of solution, that is, position of the carbon in the atom lattice. Considered physically, at such certain temperature the atom lattices and their components are in a given state of vibration, such state of vibration being characteristic for that particular certain temperature. If now suddenly a sufficient amount of heat, that is, energy, is withdrawn from the steel to cause its temperature to fall to about or below the critical temperature, such characteristic state of vibration is fixed and retained by the steel even on, and after, cooling to room temperature.

I have indeed found that by heating metals and metal alloys to temperatures above the phase conversion temperature, or while such bodies are still in their molten state during their production, the physical properties can be controlled as to magnitudes by impressing thereon the natural beat vibration characteristic of the given hardness of the particular body, the impressed natural beat vibration consisting of the natural frequency and the second characteristic frequency as above mentioned. What the particular natural beat frequency to be impressed should be is readily taken from a system of graphs previously obtained in the manner substantially as below described. What the minimum temperature of the particular body should be at which the natural beat vibration treatment should be initiated is readily determinable from the phase diagram of the system of the constituents composing the body to be treated, and is the temperature at which the phase of the actual proportions of the constituents of the body are convertible from the phase stable at normal temperature to the next adjacent phase stable at temperatures above normal. The application of the natural beat frequency is continued until the body has cooled to substantially the martensite transformation temperature, which in the case of carbon steels is about 250° C. On subsequent examination the completely cooled body is found to have the desired physical properties of which the applied natural beat frequency is characteristic.

As has been stated, the instant method may be used on the bodies while they are in the molten state, the original melt being cast in its final form, the dimensions being little altered by the instant method and the stresses and strains of quenching, or from any other source, being substantially totally absent since the body always cools off at its ordinary rate as determined by its surrounding atmosphere without any sudden interruption. Thus most machining operations, such as lathe work, grinding, milling, etc., are either eliminated or substantially reduced. The use of the instant invention, which of itself requires no extensive capital investment for the practice of the method, also results in appreciable savings by requiring fewer machine tools for the subsequent finishing of the treated body to its final dimensions, and hence less labor and power expense. It should be particularly noted that the method of my invention is most effective in that it produces its effect uniformly throughout the body including its innermost core regions, in that for the first time in any irradiation method directed to the problem of improving the physical properties of bodies full use is made of the phenomenon of resonance as compared to the complete neglect thereof in the prior known super-sonic methods.

Where the materials of the bodies are common carbon steels without alloying constituents, it has surprisingly developed that by treatment of the bodies by the instant method the physical properties thereof may be improved to values which heretofore have been associated with alloy steels and have not, or only with great difficulty, been attainable with the prior known methods. Hence the instant invention has the added advantage of substantially eliminating the use of those alloying ingredients which hitherto have been required to improve hardness, for example, to the required degree and beyond the limits of the values obtainable, without such added alloying constituents.

The foregoing, as well as the stated and other objects of the instant invention, will be clearly understood from the following description of my invention and of illustrative embodiments of apparatus to practice the method of my invention when read in connection with the hereto annexed drawing in which:

Figures 1A and 1B show schematically oscillograms of the vibratory conditions in both the testing of the materials and the treatment of the bodies to determine, respectively to produce therein, definite magnitudes in the values of their physical properties;

Figure 2 shows graphs depicting the relationship between an illustrative physical property, the hardness in kilograms per square millimeter as abscissas and the natural beat vibrations in cycles per second as ordinates of three bodies each of carbon steel of differing carbon content;

Figure 3 shows a series of graphs of the same type as shown in Figure 2 for alloyed steels of different compositions;

Figure 4 shows an illustrative apparatus for practicing the method of the instant invention in which the energy of the natural beat vibration corresponding to the desired value of a physical property is inductively impressed on the body under treatment; and

Figure 5 shows an illustrative embodiment of apparatus for practicing the instant method in which the natural beat vibration is impressed conductively upon the molten casting under treatment.

Referring to the drawing, Figures 1A and 1B are diagrams to assist in the understanding of the concept of beat vibrations in the physical sense. To obtain the necessary knowledge of the interrelation between the physical properties of bodies of materials, the materials not being chemically pure as above stated, and the natural beat vibrations requisite to the instant invention, an oscillographic record is made of the vibrations of uniformly shaped and dimensioned test pieces of the particular material. In making such records I have used cylindrical test pieces of standard dimensions, namely of 200 mm. in length and 20 mm. in diameter. Irrespective of which material, or the ratio of its constituents, it was found that the maximum natural frequency involved was of the order of some 2700 cycles per second, i. e., within the audio range. For a given material an unhardened test piece, that is, one which has not been subjected to any special hardening treatment, was first tested. The testing took the form of supporting the test piece so that it could freely vibrate on excitation, for example, by positioning the test piece across a pair of spaced knife edges or by suspending it adjacent its ends by a pair of spaced loops, and then causing it to vibrate, for example by mechanically striking it with a hammer actuated by a spring mechanism, or a relay controlled electromagnet, at appropriately spaced time intervals. The test piece would then vibrate, with damping, at its natural frequency and, as has been repeatedly stated provided the test piece was not of a chemically pure single element, the second characteristic sinusoidal oscillation would demonstrate its presence in the form of the resultant natural beat vibration. A microphone positioned near the vibrating test piece, picks up the mechanical vibrations and, preferably through the intermediary of an amplifier, transmits the vibrations electrically to a loop oscillograph. Quite obviously in the place of the microphone an electrical sound recorder may be used as the electroacoustic transducer provided precautions are taken to shield the sound recorder from any direct influence by the actuation sources for vibrating the test pieces.

When the photosensitive recording strip, which may be film or paper, of the oscillograph recorder is run at very slow speeds the envelope curve 1 of Figure 1A, that is, the natural beat vibration which is the resultant of the natural frequency oscillation and the second characteristic sinusoidal oscillation above identified, is recorded. The internodal interval T_s of one complete beat vibration, as is known, is equal to the reciprocal of the natural beat frequency which is thus accurately determinable; since the frequency of a beat vibration is equal to the difference of the two sinusoidal frequencies, which make up the beat vibration. Obviously and as is well known, the magnitude of T_s can be determined by time marks on the oscillogram or by simultaneously recording a known standard undamped frequency thereon.

When, however, the photosensitive recording strip is run at very high speeds through the recorder, the in-

dividual oscillations 2, shown within the envelope curve of Figure 1A, and of which one is shown in Figure 1B, are recorded, the successive amplitudes of the oscillations 2 varying in accordance with the beat vibration 1 and having a frequency which is the arithmetic mean of the natural frequency and the second characteristic frequency for the particular value of the physical property. The record so produced, shown in Figure 1B, is a correspondingly enlarged record for the time interval Δt of Figure 1A. Again the value of an internodal interval Δt of the record of Figure 1B is determinable in the well known manner above mentioned for determining the value T_s . Having determined Δt and its corresponding frequency, and having previously determined the natural beat frequency f_s , the values of both the natural frequency and the second characteristic frequency are readily ascertainable mathematically.

When a test piece is of magnetic material, the excitation to cause it to vibrate may be by magnetostriction by placing a solenoid about the test piece, the coil being energized from a variable, low frequency source. With such arrangement, the test piece is set into mechanical vibration by the alternating field of the solenoid, the frequency of the source being varied until the amplitude of the vibration of the test piece is a maximum. At this latter point the test piece will be vibrating at its natural frequency. With this type of an arrangement, an electro-acoustic transducer not subjectible to the direct influence of the solenoid field, for example a crystal microphone, is preferably employed to record the mechanical vibration of the test piece.

Having completed the above described observations, measurements and computations with the untreated test piece of a given material and composition, additional test pieces of the same material, composition, and dimensions but which have been treated in respect of their physical properties, for example of different degrees of hardness, are similarly examined. The particular sequence of examining the untreated and treated test pieces does of course not matter. From a comparison of the results obtained, it is readily apparent that while the natural frequency of the test pieces of a given composition of materials is unaltered, assuming measurement thereof at identical temperatures, no matter what the particular value of the physical property, for example hardness, the frequency of the natural beat vibration changes in direct relation to the increase in the value of the physical property. On plotting in a graph the observed values of the natural beat frequencies against the values of the particular physical property, in the illustrative example hardness, a fixed relationship between the two is readily noted. In other words, the natural beat vibration is a measure of the value of the physical property, hardness, of the material under test. Illustrative graphs so obtained are shown in Figures 2 and 3 in which the natural beat frequencies are plotted against the corresponding hardness values.

Figure 2 shows such graphs, the natural beat vibrations in cycles per second and the corresponding hardness values in kilograms per square millimeter, for three carbon steels which are typical of the regions in which they are positioned in the phase diagram of the iron-carbon system. Graph I is for a carbon steel in the hypo-eutectoid region, graph II for eutectoid carbon steel, and graph III for a carbon steel in the hyper-eutectoid range. The hypereutectoid steel, having sulphur and phosphorous constituents each of which is not in excess of 0.06% with both together not exceeding 0.10%, had a carbon content of some 0.45% by weight. It will be noted that in the untreated condition, the hardness of the steel was 190 kg./sq. mm., and a natural beat frequency of 4 cycles per second. The natural frequency of the test piece of this material was approximately 1950 cycles per second and remained unchanged in respect to all test pieces of this hypoeutectoid steel, while the natural beat frequency

progressively increases with increasing hardness to 16 cycles per second for the highest value of hardness obtained with test pieces of the stated configuration and dimensions, 275 kg./sq. mm. The eutectoid steel for which graph II shows the interrelation had a carbon content of 0.90% by weight and a natural frequency of some 2000 cycles per second which remained constant for all values of the hardness, while its natural beat vibration frequency increased from 4 cycles per second for a hardness of 205 kg./sq. mm., in its untreated condition to 16 cycles per second for the maximum hardness measured, 295 kg./mm.² Similarly the natural frequency of 2090 cycles per second of the test piece of hypereutectoid steel of a carbon content of 1.3% remained constant, from a hardness of 220 kg./mm.² in the untreated condition and a natural beat frequency of 3 cycles per second, to the maximum hardness measured of 308 kg./mm.² with a natural beat frequency of 20 cycles per second.

Graphs IV to IX inclusive of Figure 3 are similar to those of Figure 2, and similarly arrived at, for certain alloy steels used more or less extensively in industry. They similarly show a fixed relation between the natural beat frequencies of alloy steels to their corresponding hardness values. The alloy steels for which such graphs are given in Figure 3 had the following compositions in percentages by weight with the balance in each case iron:

Graph	C	Si	Mn	P	S	Cr	Mo	Ni	V
IV	0.40	0.35	0.75	0.020	0.022	0.92	0.20	1.2	-----
V	0.44	0.18	1.72	0.024	0.021	-----	-----	-----	0.09
VI	0.44	0.30	0.45	0.026	0.022	0.95	-----	-----	-----
VII	0.42	0.35	0.93	0.020	0.020	-----	-----	-----	-----
VIII	0.43	0.21	0.65	0.028	0.024	1.1	0.17	-----	-----
IX	0.59	0.29	0.60	0.022	0.023	-----	-----	-----	-----

The graphs of Figures 2 and 3 are illustrative only, since I have in fact prepared, as the result of examinations as above described, graphs for steels of numerous other compositions used in industry and the practical arts, all of which examinations and their graph-plotted results show the interrelation between the natural beat vibration frequency and the hardness corresponding thereto.

Not only do steels show such interrelation between the physical property values and the natural beat vibration frequency but also bodies made of metals and metal alloys of which the major ingredient is other than iron. All metal alloys having a phase diagram of the system of their components, which have at least two stable conditions of their combined constituents in exactly the same basic way show the interrelation of the physical property values of bodies made thereof and their natural beat vibration frequencies as above enumerated and described for steel and steel alloys. The alloys set forth in the textbook by Dr. M. Hansen entitled "Der Aufbau der Zweistofflegierungen," published by Verlag von Julius Springer, Berlin 1936, are herewith incorporated by reference as though actually here enumerated in detail. The graphs shown in Figures 2 and 3 are all plotted with the natural beat frequencies as the ordinate and the hardness as the abscissa. It is of course to be understood that the graphs may have some other physical property, such as strength, ductility, or grain size, etc., as the abscissa in view of the known close interrelations therebetween and the hardness of a given material and body. I have used as the abscissa in each of Figures 2 and 3 the various values of hardness as they are most readily directly measurable with available equipment, but expressly do not limit myself to the graphs being in exactly this form.

Assume now that it is required that a given value, other than that which is presently possessed by a body of known materials and known ratio of constituents, be brought about in a given physical property of the body. Since the illustrative graphs of Figures 2 and 3 are in respect

of hardness, we will assume the desired value is in the hardness. For the time being, we will further assume that the body to be treated is of both the materials and the ratio thereof for which we have previously made a graph and that it is also of the same configuration and dimensions as the test pieces for which the graph was made. The required hardness is located on the graph and the natural beat vibration corresponding thereto is read therefrom. For example, assume that an untreated body of the hypoeutectoid steel of graph I which is of the same dimensions as the test pieces in making graph I is to be given the maximum hardness of 275 kg./mm.² which is shown by point A of graph I, and discloses that the natural beat frequency is 16 cycles per second. The body is now placed in a furnace and heated to above the phase conversion temperature for 0.45% C. carbon steel, which is some 780° C. from the phase diagram for Fe:C systems. Upon reaching this temperature the body is removed from the furnace and subjected for a period of from four to ten minutes to the natural beat vibration frequency of about 0.5 kilowatt power and formed by two sinusoidal oscillations of 1950 cycles per second and 1966 cycles per second the irradiation of the body by the natural beat frequency being stopped when the body has cooled to about 250° C. Examination thereafter of the treated body at normal temperature discloses that the hardness of the body has increased from its value in the untreated body by some 22.3%, from 190 kg./mm.² to 275 kg./mm.² When testing the body now by the procedure herein before described for producing the graphs, its natural beat vibration frequency will be found to be 16 cycles per second as compared to one of 4 cycles per second in the untreated condition.

Not always is the body of a given material for which a graph has been made of the configuration and dimensions of the test pieces by which the available graphs have been made. In such case the natural frequency of the particular body to be treated may either be mathematically computed from the graph available, that is, from the additional data given thereon as to size, configuration, and natural frequency of the bodies for which the graph was made if the bodies used to make the graph are other than the normalized test pieces, or in the alternative may be experimentally determined. Thus assuming that a body made of the hypoeutectoid steel of graph I and having a natural frequency of 3000 cycles per second is to be treated so that its hardness is 275 kg./mm.² In this instance the natural beat vibration frequency used for the treatment of the body would be composed of the two sinusoidal oscillations of 3000 cycles per second and of 3016 cycles per second to give a frequency of 16 cycles per second for the corresponding natural beat vibration as shown by the ordinate of point A of graph I.

So also, an untreated body of a given material may not always be desired to be treated to impart to it the maximum possible hardness; thus the hardness value of 232 kg./mm.² may be desired for a body of the steel of graph I. Point B of graph I shows the natural beat vibration to be 12 cycles per second. Assuming the body to be treated has a natural frequency of 3000 cycles per second, the other sinusoidal oscillation making up the natural beat vibration is therefore 3012 cycles per second in frequency.

Then again it may not always be desirable or desired to increase the value of the physical property from the value the property presently has. That is, for one specific purpose or other it may become desirable to decrease the value of the hardness of bodies which may previously have been treated. Again the graph for the particular material is consulted and the beat frequency natural to the desired degree is noted. The procedure is now as above stated in respect of heating to above the phase conversion temperature and irradiating the body with the proper natural beat frequency vibration corresponding to the desired decreased value of the hardness while the body

is cooling from above its phase conversion temperature to well below such temperature. As before, when the treated body has cooled to normal temperature, it has the desired and decreased value of hardness and exhibits the corresponding natural beat vibration frequency.

In the illustrative apparatus for practicing the method of the instant invention, shown in Figure 4, a body 10 of magnetic material, after having been heated to a temperature of some 800° C. to 1,000° C., is inserted in heated condition into a solenoid coil 11, the body 10 being supported on a pair of spaced supports of fire resistant material 12. The coil 11 is connected in the output circuit of the power amplifier 13 of which the input is supplied with energy from a pair of low-frequency generators, 14a and 14b, through the transformers 15a and 15b. The output of each oscillation generator is variable in frequency, both generators being preferably provided with separator stages to eliminate hysteresis coupling effects when they are mutually detuned. One of the generators, 14a or 14b, is tuned to the frequency equal to that of the natural frequency of the body, which frequency is known in the case of mass production or is measured in the manufacture of single pieces. By the use of the graphs as above illustrated, the natural beat frequency is noted for the desired value of the physical property, and the other of the generators, 14b or 14a, is tuned to the frequency higher than that to which the first generator is tuned by the value of the corresponding natural beat frequency. Thus as the body 10 cools from above the phase conversion temperature it is sympathetically mechanically vibrated in synchronism with the impressed magnetic vibrations so that the corresponding vibratory condition of the atom lattice of the body is fixed and held while and as the temperature of the body falls to below the phase conversion temperature toward and about the martensite transformation temperature.

The specific means and apparatus used to vibrate the body under treatment by the method of the instant invention at the desired natural beat vibration frequency may be varied in many details, some of which may depend on the nature of the particular material being treated. All of the known means of the electroacoustic translation art may be so employed in principle, for example, magnetostrictive, electrostrictive, electromagnetic, or electrodynamic means, etc., and particularly in the treatment of large production items by the method of the instant invention, which items have low natural frequencies, the natural beat vibrations may be produced by purely mechanical means.

Figure 5 in schematic form shows a form of apparatus which may be used, by way of illustration, in the very practical application of the method of the instant invention to a casting immediately upon its being cast and while it is cooling and solidifying. The two member, sand or clay, mold 16 is provided with the usual pouring gate 17 and the vent pipe 18. The mold base member has a pair of ports opposite spaced edges of the mold 16, which ports are hermetically sealed by the metal electrode inserts 20, preferably hollow as shown and through which a cooling medium flows. Electrodes 20 are connected to the secondary of a transformer 21, the secondary being made of a conductor of large cross-section and of which the primary is connected to the output of a power amplifier. Like the power amplifier of Figure 4, the power amplifier of Figure 5 has a pair of low-frequency variable generators connected in parallel in the input. As a result of the low electrical resistance of the casting 19, which is solidifying from its molten state as it is cooling, very strong currents, for example of several thousand amperes, flow through the casting and the transformer secondary. By immediately so passing current through the casting while it is solidifying, and with appropriate selection of the natural beat vibration frequency in accordance with the desired value of the

physical property, the desired value of the physical property is obtained in the solidified casting. By the use of the method of the instant invention in this manner it is possible to impart to castings while still in the molten state and solidifying, properties which heretofore could only be imparted to them by appropriate treatment subsequent to their solidification. It is surmised that in this particular practice of the method of the instant invention, the electric oscillations are translated electro-dynamically into mechanical vibrations.

The method of the instant invention is readily applicable in the manufacture of steel by making use of existing apparatus in the steel plants. In such practical applications, a flow of gas may be directed about the material to be treated, and at least one of the sinusoidal oscillations making up the natural beat vibration is impressed on the flow of gas, which in turn transmits such oscillation, or oscillations as the case may be, to the material to be treated. While both sinusoidal oscillations constituting the natural beat vibration of the desired value of the physical property are preferably impressed on the stream of gas, if but one is so impressed on the gas stream then the other sinusoidal oscillation thereof is impressed directly on the material being treated. Whereas with prior irradiation methods using supersonic frequencies to improve bodies while in their solid or molten condition, matching difficulties impair the transfer of sufficient energy from a gaseous space into a solid or molten body, such difficulties are largely eliminated when using the method of the instant invention in that, firstly, the two sinusoidal oscillations comprising the natural beat frequencies lie in the resonant range of the body under treatment so that relatively little excitation energy is required to release powerful forces; and secondly, the oscillations corresponding to the natural frequency of the particular body are relatively low so that absorption of oscillatory energy by the treated material is much less than in the prior supersonic methods; hence in the instant method, in this application as in all its applications, the depth of penetration of the excitation oscillations into the body under treatment is correspondingly greater and extends to all portions of the body whether surface or internal regions. Due to the resonant effects which so appear, the entire body is uniformly affected in the instant method. The blower equipment presently installed in any steel plant irrespective of the process practiced for producing steel, may readily be used as the apparatus for practicing the instant invention. Thus, for example, the gas stream may be passed through fixed oscillation generators which are tuned or tunable, the exciting energy being taken directly from the gas stream. On the other hand, sirens with motor drives, or electroacoustic transducers of any of the known types, may be used to impress the undamped oscillation, or oscillations, of the natural beat vibration on the gas stream. Where both oscillations of the natural beat vibration are impressed on the gas stream, two tuned or tunable generators may be disposed in series, but are preferably disposed in parallel branches of the gas stream.

While my own work in the conception and development of the instant method has been with relatively crude apparatus and facilities, I stress that the method of my invention always results in reproducible effects and values. Further, as has hereinabove been stated, the instant method when applied to the treatment of castings in their molten state substantially avoids all stresses and strains in the cast body. It is known that certain alloy steels, for example stainless steel alloys, in spite of their advantages otherwise, are used rather sparingly industrially because of their tendency to crystallize so coarsely on cooling after being cast that they simply cannot be cold worked thereafter. As is well known, the size of the crystals depends on the composition of the steel and the cooling rate; in general, the slower the cooling the larger the crystals will be. If the solidification is slow, crystal-

lization proceeds from the casting exterior walls inwardly toward the center and forms macroscopic tree-like bodies of austenite, or dendrites. Since crystallization involves grain growth, the instant method is particularly advantageous in eliminating deleterious cracks in the casting which presently cause an appreciable percentage of such steel alloy castings to be rejected for further industrial use. By applying to the ingot or casting in the mold in the molten condition the natural beat frequency corresponding to the required degree of grain fineness for the particular alloy steels, the crystal size will be such that the development of cracks is avoided and hence these alloy steels take on renewed and increased industrial value and importance. Furthermore, in prior endeavors to treat castings in the molten condition while the molds, the relationship of the superficial surface of the casting to its total volume had to be relatively large in order to obtain the required degree of grain fineness, and to avoid cracking and shape distortions in view of the feasible cooling rates in such prior methods. With the use of the instant method the relationship therebetween, that is the ratio of external surface to volume of the casting, is absolutely immaterial and may be of any order. Irrespective of the volume or the surface, the physical properties of castings may, by the instant method, be given any desired values within the possible range as determined by the constituents of the castings, and be given such values throughout the casting.

Since the natural beat frequency depends on the elastic anisotropy of bodies, it follows, of course, that not only are electrically conductive bodies treatable by the instant method but also bodies of dielectric materials. As is known, the appearance of absorption lines in the spectra of bodies is computable from the elastic constants of the molecules, the observed values agreeing closely with the computed values. But the absorption spectra of metals and metal alloys differ from those of all non-metallic bodies only in that the absorption bands of the former are continuous while those of the latter are discontinuous, the continuity of the bands in the metals and metal alloys (electrical conductors) being caused by the free electrons which produce the electrical conduction, while in the non-metal bodies (electrical non-conductors) there are no free electrons and hence there is an absorptionless gap in the spectra thereof. Furthermore in an electric field every body becomes a dipole, conductors by induction and insulators by electrical charging of the dielectric. When the electrical charging and reversal of charge is by means of an alternating electrical field vibrating in synchronism with the natural frequency and the natural beat frequency—the natural beat frequency corresponding to the desired value of the physical property—the values of the physical properties of a dielectric material are readily controllable, as is readily understandable, just as are those of a conductive body by the instant method.

All the apparatus, arrangements and interconnections of the apparatus shown, or suggested, are by way of illustration only and are in no way to be considered as limitations. Various modifications thereof and therein will suggest themselves to the skilled worker in the art without departing from the scope and spirit of my instant invention.

What I claim is:

1. The method of producing any desired value within range of possible values of a physical property of a body consisting of at least two components, comprising the steps of heating the body to at least its lowermost phase conversion temperature, subjecting the heated body to the influence of beat oscillations of a frequency characteristic of the value of the physical property, the beat oscillations being the resultant of an oscillation frequency equal to the natural frequency of the body and a second oscillation of a frequency equal to the sum of the natural frequency of the body and the natural beat frequency

characteristic of the value of the physical property, and maintaining the body subject to the influence of the beat oscillations while the body cools to a temperature substantially below such phase conversion temperature.

2. The method of producing any desired value within a range of possible values in the hardness of a body consisting of at least two components, comprising the steps of heating the body to above its lowermost phase conversion temperature as determined by its components, subjecting the heated body to the influence of the natural beat frequency vibration corresponding to the value of the hardness, and maintaining the body subject to the influence of the natural beat vibration until the body has cooled to a temperature substantially below such phase conversion temperature.

3. The method of controlling the values of the physical properties of bodies of material consisting of one major ingredient and at least one minor ingredient, comprising the steps of heating the body to at least its lowermost phase conversion temperature as determined qualitatively and quantitatively by its ingredients, subjecting the heated body to beat vibration oscillations of a frequency equal to the natural beat frequency corresponding to the value of the physical properties, and permitting the body to cool while maintaining the body subject to the beat vibration oscillations.

4. The methods of controlling the values of physical properties of a metal body consisting of a major ingredient and at least one minor ingredient, comprising the steps of heating the metal body to a temperature above its lowermost phase conversion temperature, subjecting the so heated metal body to the influence of externally produced beat oscillations of a frequency equal to the frequency of the natural beat vibration corresponding to the value to be imparted to the physical properties, and permitting the metal body to cool at the rate determined by the ambient atmosphere to substantially below such phase conversion temperature while maintaining the body subjected to the influence of the beat oscillations.

5. The method of producing any one of a number of values possible in a physical property of a body of material having at least two components, comprising the steps of heating the material to its molten condition, forming the body of the molten material, subjecting the formed body while still in the molten condition to the influence of beat frequency oscillations of a frequency equal to that of the natural beat oscillation of the body corresponding to the value to be imparted to the physical property, and maintaining the body subject to the influence of the beat oscillations while the formed body solidifies.

6. The method according to claim 5 in which the beat frequency oscillations are electrically produced and applied conductively to the formed body.

7. The method of producing any desired value within the range of possible values in the hardness of a body consisting of at least two components, comprising the steps of heating the material to its molten condition, forming a body of the molten material, subjecting the formed body while in the molten condition to the influence of a beat frequency oscillation of the frequency equal to that of the natural beat vibration of the body corresponding to the value to be imparted to the hardness, and maintaining the body subject to the influence of the beat oscillation until the body has solidified and cooled.

8. The method of producing any one of a plurality of possible values in the physical properties of a body of material consisting of at least two ingredients, comprising the steps of forming a body of the material while in its heated molten condition, directing a flow of gaseous medium about the body in its molten condition, impressing upon the flow of gas beat oscillations of a frequency equal to that of the natural beat vibration of the formed body corresponding to the value to be imparted to the physical properties, the flow of gas impressing the beat oscillations in turn on the formed body of the molten

material, and maintaining the application of the beat oscillations while the body cools and solidifies.

9. The method of producing any desired value within the range of possible values in the hardness of a body of metal consisting of at least two ingredients, comprising the steps of forming a body of the material while in a heated molten condition, directing a flow of gas about the formed body, impressing upon the flow of gas at least one of a pair of sustained oscillations forming a beat frequency oscillation of which the frequency is equal to that of the natural beat vibration corresponding to the degree of hardness to be imparted thereto, and maintaining the gas flow and the impressed oscillation while the metal body cools to at least complete solidification.

10. The method of producing any desired value within the range of possible values which a physical property of carbon steels may have as the result of its composition, comprising the steps of heating the carbon steel body to above its lowermost phase conversion temperature as determined qualitatively and quantitatively by its carbon content, subjecting the steel body to the influence of beat frequency oscillations of the frequency equal to the natural beat frequency corresponding to the value to be imparted to the physical properties, and maintaining the steel body under the influence of the beat frequency oscillations as it cools to substantially the martensite transformation.

11. The method of producing any desired value of hardness within the range of possible values of the hardness of carbon steels, comprising the steps of heating a body of carbon steel to at least the lower of its phase conversion temperatures of the particular carbon steel, subjecting the steel body in the heated condition to the influence of beat oscillations of which the frequency is equal to that of the natural beat vibration of the particular carbon steel corresponding to the value to be imparted to the hardness, and maintaining the steel body subject to the influence of the beat frequency oscillations as it cools to below about 400° C.

12. The method according to claim 11 in which the carbon steel body is heated to a temperature lying in the range from such lower phase conversion temperature to about 1000° C., the steel body is subjected to the influence of the beat oscillations for a period of from four to ten minutes, and the body is permitted to cool at the rate determined by the ambient temperature.

13. The method according to claim 11 in which the beat oscillations are electrically generated and conductively applied to the steel body.

14. The method according to claim 11 in which the beat oscillations are electrically generated and inductively applied to the steel body.

15. The method of producing any desired value within the range of possible values in the hardness of a carbon steel body, comprising the steps of casting a steel body, subjecting the steel casting while still in its molten condition to the influence of electrically produced beat frequency oscillations of a frequency equal to that of the natural beat vibration of the casting at normal temperatures corresponding to the value to be imparted to the hardness, and maintaining the casting subject to the influence of the beat oscillations until the casting has solidified and cooled to substantially the temperature of the martensite region.

16. The method according to claim 15 in which the beat oscillations are applied to the casting by electrical conduction, and the casting is permitted to cool at the rate determined by the ambient atmosphere.

References Cited in the file of this patent

UNITED STATES PATENTS

1,061,760 Lash May 13, 1913

(Other references on following page)