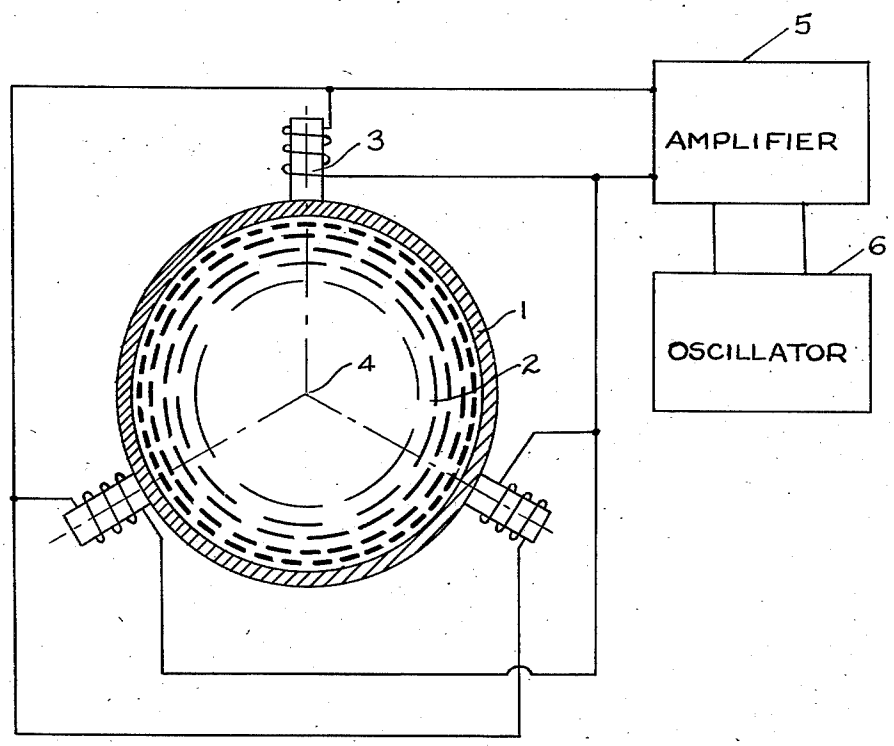
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METHOD OF HARDENING FERROUS METALS

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METHOD OF HARDENING FERROUS METALS

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11 Claims. (Cl. 148—21.55)

This invention relates to improvements in the hardening of ferrous metals and more particularly to an improved method of agitating the quenching medium and increasing the effectiveness of the quenching operation with the aid of sonic waves.

The purpose of quenching steels and ferrous metals generally is to produce a completely martensitic structure at least on the surface as anything less than this is incomplete hardening and results in inferior mechanical properties. Accordingly for highest mechanical properties quenching, whether continuous or interrupted, should be controlled with precision.

Precision and uniformity are not generally obtained with conventional liquid quenches such as water, brine, oil, molten salt etc. as during the process of quenching for hardening a layer of insulating vapor forms immediately upon immersion into the quench. This retards the cooling until the vapor layer is broken down so that the quenching fluid may contact the metal. Since the stability and duration of the vapor film on different sections of a given part varies widely depending on several complex factors, uneven cooling results and this condition contributes to warpage, distortion, stress concentration, and cracking.

It is known that agitation will shorten the duration of the existence of the vapor film and will increase the effectiveness of liquid quenches to some extent. However such conventional methods of agitating the quenching liquid are relatively slight in comparison with the much greater effect which is attainable by the introduction of high frequency sonic waves into the quench according to the teachings of my present invention more fully hereinafter described.

The retarded cooling which results from the formation of the vapor film on conventional liquid quenching represents a subsantial item of increased cost of the hardened products as it is common practice to add alloying elements which reduce the critical cooling rate sufficiently so that even the less efficient quenches may result in substantially full hardening. However, such alloying elements are for the most part in short supply and the alloy steels are more costly to purchase and are more difficult to machine.

My investigations confirm the experience of prior workers relative to the undesirable effects of the insulating vapor layer, but show how the film may be instantly eliminated with a marked increase in quenching effectiveness. I also find that a much better hardened structure and a more favorable distribution of residual stress is assured when quenching is conducted so that the high frequency sound vibrations insures the instantaneous removal of the vapor film.

It is, therefore, one of the outstanding objects of this invention to bring about a marked increase in the agitation of liquid quenching baths during the hardening of ferrous metals.

It is also an object of this invention to increase substantially the quenching effectiveness of liquid quench baths.

Another object of this invention is to instantaneously remove or to eliminate the formation of the vapor layer characteristic of conventional quenching practice.

Another object of this invention is to introduce high frequency sound vibrations into liquid quenching baths on continuous cooling to result in the formation of martensite with a more favorable distribution of residual stress.

It is also an object of this invention to increase the effectiveness of hot quenching baths on interrupted quenching and to adopt the use of these treatments to greater advantage.

An important object of this invention is to bring about a marked saving in alloys consumed in compensating for the relatively slower quenching action of conventional quenching mediums.

Another object of this invention is directed to the "hammering" effect of the powerful vibrations in the quenching liquid to result in the formation of surface compressive stress by work hardening.

A further and important object of this invention is to minimize distortion and warpage on hardening.

A related object is also to minimize high stress concentrations and to avoid cracking.

It is also an object of this invention to obtain a higher degree of uniformity from hardened parts than has heretofore been attainable.

These and other objects that will be brought out hereinafter may be attained according to my invention by the introduction of high frequency vibrations of sufficient power into the quench or applied directly to the ferrous metal during quenching.

Further objects and advantages of this invention will become apparent in the following detailed description of an embodiment thereof:

The drawing is a cross sectional view of a quench tank showing one form in which my invention may be applied.

Referring to the drawing the quench tank has metal walls **1** which are circular although other shapes are also satisfactory. The quenching fluid **2** is water and is enclosed within the confines of the container walls **1**.

For the purpose of delivering sonic energy of high intensity in sufficient quantity to effect a high degree of agitation of the quenching fluid **2** I have attached three magnetostriction transducers **3** to the container walls **1**.

These magnetostriction transducers **3** employ a stack of this nickel iron cobalt alloy laminations which contracts and expands under the influence of a magnetic field set up in the windings to form a resonant system at about 25,000 cycles per second. The transducers **3** are attached to the outer surface of the container wall **1** and the transducer enclosure is filled with oil which is cooled by a finned tube through which tap water is circulated for heat dissipation. Other forms of magnetostrictive transducers **3** may be employed such as nickel or nickel alloy tubes. Also other types of electro-acoustic transducers may be used such as the piezo-electric crystals.

The magnetostrictive transducers are mounted on the outer surface of the container wall **1** so that they are in intimate contact and the sonic energy delivered will be focused in the center **4** of the quench tank. The transducers **3** may be oscillated in the usual manner from a suitable source of high frequency oscillations such as an electronic oscillator **6** and an electronic amplifier **5**.

Violent agitation will be set up in the center **4** of the quench tank. In order to insure sufficient agitation it may be desirable to add additional transducers **3**. In the case of long parts to be quenched additional bands of transducers **3** may be added to increase the turbulence over a greater depth of the quenching fluid **2**.

The degree of turbulence and the efficiency of the removal of the vapor film will be much greater when the

natural period of vibration of the container walls 1 is such that it is in a state of resonance with respect to the frequency of the sonic waves causing the vibration.

While one embodiment of the application of the principles of this invention is illustrated it will be understood that removal of the vapor film and increased agitation is obtained over a wide range of frequencies from about 100 cycles per second to about 5 megacycles per second and many types of sonic generators may be employed for this purpose such as piezo-electric, magnetostriction, electro-magnetic generators, and other mechanical or elctrical means including pneumatic vibrators, sirens, whistles, etc.

Also it is not necessary that the transducer be attached to the container walls of the quench tank as an alternate and satisfactory method consists in inserting the transducer in the quenching fluid or the vibrations may be applied directly to the ferrous metal being quenched.

Also the improvement in quenching is applicable to all commonly used liquid quenching mediums including oil, brine, water, molten salt, etc. High frequency vibrations are particularly effective in quenching parts which are relatively inaccessible to the quench such as blind holes, small holes, fine threads, knurled surfaces, small recesses etc.

Without sonic energy as described in the foregoing embodiment of my invention, the vapor film formed on the surface of the ferrous metal being quenched, retards the quenching considerably. In this connection there are three distinct stages of cooling with conventional liquid quenches which will be reviewed to provide a background for a better understanding and appreciation of the teachings of my invention. When a one quarter inch round piece of steel is quenched from 1525° F. into still water the three stages of cooling which will be observed are:

Stage A. Vapor blanket cooling.—In this first stage a thin stable vapor film surrounds the hot metal. Cooling is by conduction and radiation through the gaseous film and is relatively slow. In the example of the one quarter inch round steel cited the steel will cool about 325° F. in about 5 seconds with the vapor film on the steel.

Stage B. Vapor transport cooling.—At the termination of the A stage, wetting of the metal surface occurs. Vapor forms copiously in bubbles and is carried away by gravity and convection. This is the fastest and shortest stage of cooling in which the one quarter inch round steel will cool about 400° F. in about one second.

Stage C. Liquid cooling.—When the surface temperature of the metal approaches the boiling point of the quenching liquid, vapor no longer forms so cooling is by conduction and convection and the cooling is quite slow. The one quarter inch round steel will cool about 500° F. in about 8 seconds.

From the foregoing description of the three stages of cooling and the cooling rates at the center of a one quarter inch round steel, which is characteristic of all liquid quenching mediums, it will be apparent that quenching is not uniform and frequently occurs at widely different rates on various sections of a given part. This lack of uniformity results in warpage, distortion, stress concentration, and cracking which can be avoided or minimized by my invention which removes the vapor layer and insures uniform quenching even on parts which differ considerably in section.

Furthermore when sonic energy is introduced into the quench according to my invention, stage A is practically eliminated and there is substantially no slow period of quenching according to stage C on conventional cooling. I find that the introduction of sonic energy of proper intensity to produce a state of intense turbulence will result in a much faster cooling rate than the conventional quenches without sonic vibration. More specifically, my invention results in a cooling rate, extending approximately from the austenitizing temperature to the quenching bath temperature, which is at least as rapid and usually greater than that which prevails during stage B of conventional quenching.

It should be noted in this connection that the use of brine instead of water or the addition of agitation by conventional methods will tend to increase the cooling rate somewhat during stage A and C but will not appreciably change the conditions described for stage C.

Neither the frequency nor the amplitude of the vibrations are separately of critical importance. However it is important that the power output and the frequency-amplitude product be high as this makes for high values of acceleration and high degrees of turbulence imparted to the quenching medium.

In water or brine and in liquids in general with a velocity of sound of about 3900 feet per second the wave lengths range from about 2.3 to about 0.00008 inches.

Sonic energy is transmitted by waves that take the same form as sound waves and are alternate, regularly spaced compressions and rarefactions. High frequency vibratory motions or sonic waves are gnerally classified as "audible" or "ultrasonic." The former have frequencies less than about 18,000 cycles per second which is about the limit of hearing for the human ear. The latter have frequencies above about 18,000 cycles per second, which is in the inaudable range, and may extend into millions of cycles per second.

To understand the powerful effects that these high frequency vibrations can exert upon materials against which they are directed it should be noted that tremendous accelerations are involved. Gravity produces an increase in velocity of 32.2 feet per second on a falling body. Ordinary mechanical vibration such as is produced by mechanical stirrers in a quench bath applies an acceleration roughly several times that of gravity. Under high frequency vibration, however, the "shaking" action may be repeated in the liquid quench first in one direction and then in the opposite direction producing an acceleration as high as 6,250 miles per second with frequencies of about one half million cycles per second.

I find that either audible or ultrasonic vibrations can be used to provide the desired turbulence in the quench. However the power should be high, and should be at least 25 watts per square inch of metal surface being quenched. This is a minimum value and preferably higher intensities should be used. The lowest frequency which is effective is about 100 cycles per second and the upper limit is about 5 megacycles. Due to the difficulty of generating large amounts of power with frequencies over 100,000 cycles per second with presently available equipment, the preferable operating range is below about 100,000 cycles per second.

The higher frequencies above about 100,000 cycles per second can be most conveniently generated by piezoelectric transducers generally of quartz crystals or barium titanate. Such installations are limited to the quenching of small parts due to the present power limitations of this type of equipment. Also the piezoelectric transducers are fragile and require considerable care to avoid breakage.

In the frequency range from about 10,000 to about 100,000 cycles per second magnetostriction transmitters are better adapted. The magnetostriction transducers generally consist of a nickel or nickel alloy laminations or tube in a magnetic circuit. A coil is placed around the rod and it is energized by electric current of high frequency. Due to the resulting magnetic field the rod expands or contracts. For example, a nickel tube nine inches long by one inch in diameter by $\frac{1}{32}$ inch wall thickness may be made to vibrate with an amplitude up to about 0.001 centimeters which is the rupture point of the nickel. The movement may be transmitted to a radiating membrane or disc directed into the liquid quench so that the vibrations are focused on the work.

In the lower frequency range below about 1800 cycles per second sonic energy can also be generated by motor

generator sets. Such installations are capable of delivering several hundred kilowatts of energy in the form of sonic energy into the quenching liquid. The cost of energy generated by motor driven alternators is considerably less than by electric generators. Mechanical vibrators such as pneumatic vibration generators are applicable to the practice of this invention and may be used in the lower frequency range below about 500 cycles per second.

With a power of 100 watts per square inch, the pressure, particle velocity, displacement, and acceleration are tabulated herewith for a water or brine quenching medium, the vapor insulating layer formed on the surface of the steel part being quenched, and for the steel part itself. This data applies to frequencies of 10,000 and 500,000 cycles per second.

[Power: 100 watts per square inch.]

	Pressure, Pounds per Square Inch	Peak Particle Velocity, Inches per Second	10,000 cycles per second		500,000 cycles per second	
			Peak to Peak Displacement, Inches	Peak Acceleration, "G"	Peak to Peak Displacement, Inches	Peak Acceleration, "G"
Vapor Layer	1.64	1074	0.0342	175,600	0.000171	8,780,000
Brine or Water Quench	96.5	18.2	0.0579	2,970	0.0000029	148,500
Steel	503	3.5	0.000111	572	0.00000056	28,600

The peak to peak displacement for other frequencies can readily be calculated from the formula

$$D\,(\text{displacement}) = \frac{V\,(\text{velocity})}{3.14 \times F\,(\text{frequency})}$$

The peak acceleration for other frequencies can readily be calculated from the formula

$$A\,(\text{acceleration}) = \frac{2 \times 3.14 \times F\,(\text{frequency}) \times V\,(\text{velocity})}{G\,(\text{acceleration due to gravity})}$$

I believe that the principal reason for the instantaneous removal of the vapor film on the quenched ferrous metal under conditions of sonic vibrations is due to the tremendous accelerations involved as will be observed from the foregoing table.

Cavitation has an important effect on the removal of gases and vapor films from liquid quenching mediums. In practicing my invention for introducing high frequency vibrations into the quench bath, the transducer must be coupled to the output medium and must match the input power for resonant conditions. Also maximum agitation and turbulence for fast and uniform quenching are best obtained under conditions of cavitation.

When sonic energy moves through a liquid quenching medium, creating alternate compressions and rarefactions in the quench, the individual molecules of the liquid are violently agitated. Cavitation is caused by very violent agitation of the liquid. Just the right intensity of sonic energy which is a combination of frequency and amplitude will cause very violent and intense agitation, and will result in the formation of vacuum pockets. When these pockets collapse an instant after formation, the effective pressure is equal to several thousand atmospheres. With sufficient power input cavitation has the effect of driving dissolved gas and air out of the liquid quench. This produces pockets large enough to be seen with the naked eye at frequencies between about 8,000 to about 30,000 cycles per second in which range cavitation is most pronounced although the effect is also powerful at frequencies up to about 100,000 cycles per second.

I find that when high frequency sonic energy is imparted to the ferrous metal during the process of hardening wherein austenite transforms to hard martensite, higher hardness and a more favorable distribution of residual stress results. As is known to metallurgists and heat treaters skilled in the art and science of hardening, a somewhat related phenomenon occurs on induction hardening whereby ferrous metals are heated for hardening by induced currents at high frequencies commonly up to about several hundred thousand cycles per second. However the introduction of high frequency sonic energy by my invention into the quench or applied directly to the ferrous metal during the transformation of the austenite to martensite is distinctly more powerful in its effectiveness than the introduction of high frequency magnetic vibrations in induction hardening wherein the high frequency energy is applied only during the heating and not during the quenching of ferrous metals.

My invention is also particularly effective in increasing the quenching power of hot quenching mediums used in interrupted quenching. The aims, methods, and advantages of this treatment, which was originally developed by me, are described in detail in my U. S. patent application Serial No. 320,998, filed February 27, 1940, now U. S. Patent 2,780,205. One of the difficulties with interrupted quench hardening treatments, variously termed Step Quenching, Martempering, or Marquenching, is the limitation of section which can be treated. This has resulted in the use of more alloys and low bath temperatures. Both of these expedients nullify to some extent the advantages of this treatment. The use of sonic energy according to the principles of my invention to agitate the liquid quench bath maintained at about or above the range of martensite formation, extends greatly the usefulness and scope of interrupted quench hardening treatments.

In particular, my invention increases considerably the quenching power of hot oil which without high frequency vibration is relatively ineffective in this respect. Hot oil is less expensive than molten salt and has other desirable characteristics. Work can be quenched directly from cyanide salts into oil whereas an explosive hazard exists when cyanides are mixed with the commonly used nitrate-nitrite quenching salts. My invention greatly increases the quenching power of hot baths and in particular permits greater utilization of the desirable features of hot quenching oils.

The standard method of expressing the severity of quench is the "Grossman H value" or as it is commonly expressed, the "H" value. A description of the method of calculating this is found in the chapter entitled "Hardenability of Steel," p. 495 of the 1948 edition of the "Metals Handbook" published by the American Society for Metals. Prior investigators have calculated the H value for oil and brine with and without agitation.

My investigations into the severity of quench confirms the work of prior investigators and also shows the H value of hot salt at 400° F. to be slightly higher than oil at room temperature for equivalent degrees of agitation. Furthermore my calculations show that the introduction of sonic energy into the quench according to the principles of my invention will increase the H value by at least about 50% over the maximum obtained in commercial practice without sonic vibration for such liquid

quenching mediums as oil, brine, water, molten salt, etc.

Tabulated herewith are the H values for several commonly used quenching mediums with no agitation, conventional agitation, and high frequency agitation according to the principles of my invention.

H value (severity of quench) for various liquid quenching mediums with and without sonic energy

	Conventional Practice	Vibrated with Sonic Energy (Minimum value)
Oil:		
Still	0.25/0.30	
Violent Agitation	0.80/1.10	
High Frequency Agitation		1.65
Brine:		
Still	2.0	
Violent Agitation	5.0	
High Frequency Agitation		7.5
Hot Salt, 400° F.:		
Still	0.30	
Violent Agitation	1.20	
High Frequency Agitation		1.80

The foregoing examples of minimum values of severity of quench for high frequency vibration are for a magnetostriction transducer operating at resonant vibration of about 20,000 cycles per second and having a power output of about 200 watts per square inch.

It is to be understood that specific figures as to frequencies, accelerations, power etc. have been given by way of illustration and with reference to the treatment of specific applications.

The examples of operating procedure hereinbefore outlined were calculated to effect a marked improvement in quenching effectiveness and to instantly remove the vapor layer which retards the quenching action. Also it is planned to effect a marked saving in alloys formerly found to be necessary to compensate for the slower quenching rate of conventional liquid quenches.

It will be understood that the vibrations may be introduced into the quench or applied directly to the ferrous metal itself. Either method may be used to obtain the stated benefits from the sonic energy and yet the quenching will fall within the spirit and scope of my invention.

It will be understood that the vibration may be carried on at frequencies outside of the preferred range of about 1,000 to about 100,000 cycles per second and within the broader range of about 100 to about 5,000,000 cycles per second in which case the frequency-amplitude product should be high together with sufficient power input to result in a marked degree of agitation and turbulence. Since it is also highly desirable to vibrate the quench under essentially resonant conditions for maximum effectiveness it becomes necessary to use a range of frequencies. However in the light of the above disclosures it becomes a relatively simple matter for one skilled in the art to determine by preliminary tests the precise frequency and energy input value that need be maintained to obtain the desired turbulence and agitation in the quenching bath.

I claim:

1. In a process of hardening ferrous metals by quenching from above the critical temperature in a liquid quenching medium, the step of subjecting the said quenching medium to the influence of sonic vibrations of frequencies between about 100 cycles per second and 5 megacycles per second under conditions of resonance thereby increasing the degree of agitation and turbulence to produce cavitation and to provide faster quenching of the said ferrous metals.

2. The process of hardening ferrous metals which consists in heating above the critical temperature, quenching into a liquid quenching bath and subjecting the said quenching bath to high frequency mechanical vibrations between about 100 cycles per second and 5 megacycles with a power intensity of at least 25 watts per square inch.

3. The process of hardening ferrous metals which consists in heating above the critical temperature, quenching into a liquid quenching bath and in subjecting the said ferrous metals to high frequency mechanical vibrations between about 8,000 and 30,000 cycles under conditions of resonance to produce cavitation while immersed in the said bath.

4. The process of hardening ferrous metals which consists in heating above the critical temperature, quenching into a liquid quenching bath and in subjecting the said ferrous metals to high frequency mechanical vibrations between about 8,000 and 30,000 cycles with a power intensity of at least 25 watts per square inch.

5. A method of hardening ferrous metals comprising the steps of heating above its critical temperature for a sufficient length of time to convert it substantially to the austenitic state; quenching the ferrous metal to a subcritical temperature below 1000° F. and above the range within which austenite transforms to martensite on cooling, and in subjecting the ferrous metal to the influence of high frequency sonic vibrations between about 100 cycles per second and 5 megacycles per second with a power intensity of at least 25 watts per square inch while immersed in the said bath; and thereafter removing the ferrous metal from the liquid bath and cooling it to room temperature.

6. The process of claim 2 wherein the high frequency vibrations have such frequencies as to be in resonance with the natural frequencies of the said liquid quenching bath.

7. The process of claim 2 wherein the high frequency vibrations have such frequencies as to cause the said quenching bath to be agitated in a state of cavitation.

8. The method of hardening steel which comprises heating the said steel above the critical temperature range to render it austenitic, quenching the said steel into a molten bath maintained at a temperature range below about 800° F. but above about 400° F., holding the said steel for a predetermined time interval sufficient to cool the said steel to within that temperature range, subjecting the said bath to sonic vibrations between about 100 cycles per second and 5 megacycles per second with a power intensity of not less than about 25 watts per square inch while the said steel is immersed in the said bath, and finally air cooling the said steel to room temperature.

9. The method of claim 8 wherein the sonic vibrations have such frequencies as to be at least approximately in resonance with the natural frequencies of the said molten bath.

10. A hardenable steel treatment including heating the steel above its critical temperature to render it austenitic, quenching the steel at a rate at least equal to its critical cooling rate into a liquid bath at substantially room temperature, all the while subjecting the liquid bath to mechanical vibrations of frequencies between about 500 cycles per second and about 500,000 cycles per second with an intensity of at least 25 watts per square inch while the steel is immersed in the bath.

11. In hardening steels, the method of improving the effectiveness and uniformity of liquid quenching which method consists in heating the steel to render it austenitic, quenching the steel into a suitable liquid vibrated at a frequency between about 100 cycles per second and about 5 megacycles per second with a power intensity of at least 25 watts per square inch and under conditions of resonance.

References Cited in the file of this patent

The Washington Post, p. 6R, March 20, 1949.

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 2,798,832 July 9, 1957

Richard F. Harvey

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 1, line 50, for "subsantial" read -- substantial --; column 2, line 47, for "this" read -- thin --; line 58, after "transducers" insert the numeral -- 3 --; column 3, lines 11 and 12, for "eletrical" read -- electrical --; column 4, line 21, for "gnerally" read -- generally --; column 5, line 5, for "electric" read -- electronic --.

Signed and sealed this 24th day of September 1957.

(SEAL)
Attest:
KARL H. AXLINE
Attesting Officer

ROBERT C. WATSON
Commissioner of Patents